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Replacement Of Natural Fine Aggregate With Granular Slag - A Waste Industrial By-Product In Cement Mortar Applications As An Alternative Construction Materials

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ABSTRACT

The construction industry is the largest consumer of natural resources which led to depletion of good quality natural sand (Fine aggregates). This situation led us to explore alternative materials and granular slag a waste industrial byproduct is one such material identified for utilization it as replacement of natural sand. This paper highlights upon the feasibility study for the utilization of granular slag as replacement of natural fine aggregate in construction applications (Masonry & plastering). In this investigation, cement mortar mixes 1:3, 1:4, 1:5 & 1:6 by volume were selected for 0, 25, 50, 75 & 100% replacements of natural sand with granular slag for w/c ratios of 0.60, 0.65, 0.70 & 0.72 respectively. The study gave comparative results for mortar flow behaviors, compressive & split tensile strengths, brick mortar crushing & pulls strengths and their co-relations. The study comprises of The experimental results obtained show that partial substitution of ordinary sand by slag gives better results in both the applications i.e. masonry & plastering. The sand replacement from 50 to 75% improved mortar flow properties by 7%, the compressive strength improved by 11 to 15 % for the replacement level from 25 to 75%. At the same time brick mortar crushing & pull strengths improved by 10 to 13% at 50 to 75% replacement levels. The co-relation between mortar compressive/split tensile strengths & brick crushing/pull strengths shows linear dependencies on each others. The study concluded that granular could be utilized as alternative construction material for natural sand in masonry & plastering applications either partially or fully.

Key words: Granular slag, compressive strength, split tensile strength, mortar adhesion strength

INTRODUCTION

In the production of iron and steel, fluxes (limestone and/or dolomite) are charged into blast furnace along with coke for fuel. The coke is combusted to produce carbon monoxide, which reduces the iron ore into a molten iron product. Fluxing agents separate impurities and Slag is produced during separation of molten steel. BF slag is a nonmetallic co-product primarily consists of silicates, aluminosilicates, and calcium-alumina-silicates. The molten slag which absorbs much of the sulfur from the charge, comprises about 20 percent by mass of iron production. Figure 1 presents a general schematic view which depicts the BF feedstock and the production of blast furnace co-products (iron and slag).

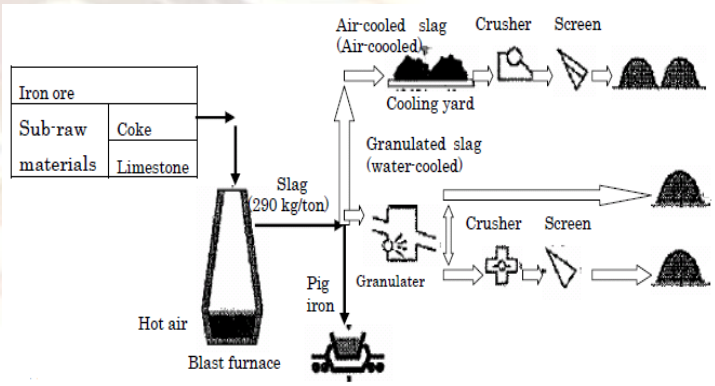

Figure 1 General Schematic view of blast furnace operation and slag production

RESEARCH SIGNIFICANCE & SCOPE

Presently, use of slag in India is to the tune of 15 to 20 % by cement industry rest is mostly unused. The use of industrial by-products in mortar not only helps in reducing green house gases but helps in making environmentally friendly construction materials. Fine aggregates are part of all the three major applications of construction namely masonry, plastering & concreting. Due to increased construction activities in India, availability of natural fine aggregates are depleting by each passing day due to construction of large water storage dams on the rivers. Present research study explores the possibility of using granular slag as replacement of natural sand in mortar (Masonry & plastering applications). In this investigation, cement mortar mixes 1:3, 1:4, 1:5 & 1:6 by volume were selected for 0, 25, 50, 75 & 100% replacements of natural sand with granular slag for w/c ratios of 0.60, 0.65, 0.70 & 0.72 respectively. The study gave comparative results for mortar flow behaviors, compressive & split tensile strengths,

brick mortar crushing & pulls strengths and their co-relations.

EXPERIMENTAL INVESTIGATION

This section describes physical & chemical properties of materials used, mix proportioning, mortar properties, test-setup.

Materials

Granular slag from the local steel making plant, natural sand from the local river shown in Figure 2, satisfying IS 383-1993 was used, Portland pozzolana cement confirming to IS 1489 (Part 1):1993 were used . All the chemical & physical properties of the materials are given in the Table 1

Table 1 – Physical & Chemical Properties of Materials

Slag				**Natural Sand**
Chemical Analysis		**Physical Properties**		**Physical Properties**
Constituents	(%)	Specific Gravity	2.38	2.65
Loss on Ignition	1.80	Water Absorption	0.39%	0.65%
Silica	30.20	Dry loose bulk density(DLBD)	1058 Kg/cum	1468 Kg/cum
R_2O_3	20.20	Soundness	0.90%	0.90%
Fe_2O_3	0.60	Fineness Modulus	3.14	2.64
Al_2O_3	19.60	Zone	I	II
Cao	32.40	Silt (Volume)	1.38 %	2%
MgO	9.26			-
SO_2	0.27			-
Insoluble matters	0.80			-

Cement-(Portland Pozzolana Cement)			
Physical Properties		**Chemical Properties**	
Specific Surface	380 m^2/kg	Total Loss on Ignition	1.40%
Setting time – Initial	195 minutes	Magnesia	1.40%
Setting time Final	280 minutes	Sulphuric Anhydride	2.06%
Soundness test by -Le-chatelier method	0.50%	Insoluble residue	26.0%
Soundness test by Auto Clave method	0.06%		
Compressive strength after - 3day	34.9 Mpa		
Compressive strength after - 7 days	44.2 Mpa		
Compressive strength after - 28 days	61.4 Mpa		
Chloride	0.04%		
Fly ash	28%		

Figure 2 – View of Granular slag sand & natural sand

Mortar Properties

In construction work, masonry units are bound together with the help of cement & fine aggregates (below 4.75 mm size) paste which is termed as Mortar. It is defined in IS 2250 – 1995 as,

Mortar is a homogeneous mixture, produced by intimately mixing cementitious materials, water and inert materials, such as sand to the required consistency for use in building together with masonry units.

The safety, strength & durability of the resulting wall or any such structure depend on the quality of the mortar used as binding medium. Mortar serves following functions,

- It provides a binding force or cohesion between the structural units
- It act as a medium for distributing the forces throughout the structure uniformly

- It imparts to the structure additional strength and resistance against water penetration

The essential properties/qualities of a mortar are listed below,

- The mortar mix should be easily workable
- The mortar should be sufficiently plastic
- The mortar should be capable of retaining sufficient water during its application
- The mortar should not react with construction units like bricks

Mix Proportions

The study was done to find out results after replacing natural sand with granular slag by taking various proportions 1:3, 1:4, 1:5 & 1:6 as per the IS 2250 – 1995. In each mixes, natural sand confirming the IS – 2116 – 1999 was replaced with granular slag by 0% (Standard mix), 25%, 50%, 75%, & 100% given in Table 2.

Table 2 – Proportion & Replacement Details

Mix No.	Proportions	Natural Sand (%)	Slag Sand (%)
Mix I, II,III, IV,	1:3, 1:4, 1:5, 1:6	100	0
		75	25
		50	50
		25	75
		0	100

Test-Setup

The test was carried out as per the IS code 2386 (part VI) – 1997 "measurement of mortar making properties of fine aggregate". The flow was finalized for 100± 5 mm for each standard mix and based on the flow; w/c ratios were selected given in Figure & Table 3.

Figure & Table 3 – W/C ratio for standard flow

W/C Ratio for standarad flow of 100+_5 mm flow	
Mix proportions	W/c Ratio
1:3	0.6
1:4	0.65
1:5	0.7
1:6	0.72

In masonry work, mortar needs to take compressive strength which is essential property of mortar. For making the mortar cubes, IS 2250-1995 (Code of practice for preparation and use of masonry mortar) was referred. For each proportions i.e. 1:3, 1:4, 1:5 & 1:6 total five mixes were prepared by replacing natural sand with slag sand by 0,25,50,75 & 100 %. For each mix, set of 3 cubes of 50 mm^2 were filled and tested for compressive & split strengths after 7 & 28 days time. At the same time, mortar used in masonry & plastering are required to take certain amount of tensile stresses due to variation in ambient temperatures (day night, seasonal), internal shrinkage stresses due to plastic and drying conditions. In order to study behavior of slag against tensile stresses with various replacement levels, cubes were tested for split tensile strength after 28 days time. The cubes of 50 mm^2 were prepared as per IS 4031 (part 6) – 1988 for mix proportions of 1:3,1:4,1:5 & 1:6 with replacement of slag sand with 0, 25, 50, 75 & 100 % shown in Figure 4.

Figure 4 – Testing of mortar for compressive & split tensile strengths

Mortar is used in masonry work for binding the two masonry units. The primary object of masonry bond is to give strength to masonry unit but it may also be employed to create artistic effects

when the brickwork is exposed to view. The bond mainly takes compressive stresses arises due to load transferred by the above units. The brick was used as per IS 1077 -1997 & mortar was prepared as per the requirements of IS 2250 – 1995, IS 3495 (part I)-1998 & 2212 – 1998. The mortar of 10 mm thick layer was applied in between the two bricks and kept it for moist curing. A set of bricks comprises three units for each proportion of 1:3, 1:4, 1:5 & 1:6 with slag sand replacement of 0,25,50,75 & 100 %. Set of bricks were tested for mortar joint crushing strength after 7 days time. The bricks were kept under compression testing machine and uniformly compression load was applied. The load at which brick work gets crushed divided by the area of mortar gave mortar joint crushing strength as shown in Figure 5.

Figure 5 – Testing of brick joint crushing strength

In this test, mortar joint's pull or adhesive capacity was tested against the force applied for pulling mortar joint between two cross bricks of burnt clay type. The bricks were applied 10 mm thick mortar for proportions of 1:3,1:4,1:5 & 1:6 with slag sand replacement of 0,25,50,75 & 100 %. After 7 days of curing the mortar joint bond strength was tested in Universal testing machine. Cross bricks were kept in-between the jaws of UTM by means of metal sling. Load was applied till the cross bricks pull apart and separated completely from each other. The load at which brick joint fails divided by the mortar area in contact with both the bricks gave pull/adhesive strength of brick joints as shown in Figure 6.

Figure 6 – Testing of brick joint pull strengths

RESULTS & DISCUSSION

The result of the investigation for the replacements of natural sand with granular slag (volumetrically) was discussed. The replacement was taken as 0, 25, 50, 75 & 100% for 1:3, 1:4, 1:5 & 1:6 mortar mixes proportions for 0.60, 0.65, 0.70 & 0.72 w/s ratios respectively are discussed below,

Mortar Flow

The results indicated that in the proportions of 1:3 & 1:4, the flow increases by 7% upto slag replacement level of 75% & 50% respectively and at 100% replacement level, it came down to 5% & 2% respectively. In mix proportions of 1:5 & 1:6, flow increases upto the replacement level of 50% by 2 & 1% but later decreases 3 & 5% at 100% replacement level respectively. The study clearly indicated that in rich mixes with finer particles, granular Slag reduced internal particle frictions which enhanced its flow properties at the same time with lesser cement content, flow decreased shown in Figure 7.

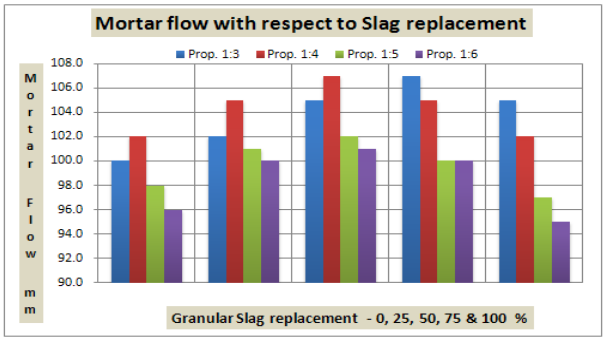

Figure 7 – Mortar Flow and W/C Ratio

Mortar Compressive strength

It was observed that in the mix proportions of 1:3 & 1:4, compressive strength increased upto the replacement level of 75% by 14.66 & 16.42% respectively and in 1:5 & 1: 6 mix proportions the increase in strength was observed to the tune of 11.19 & 11.7% at 50% replacement level. The increase in strengths at 100% replacement was noted as 5.41, 6.9 & 1.09% in 1:3, 1:4 & 1:5 mix proportions and in 1:6 it was below 0.82% compare to 0% replacements as shown in Figure 8.

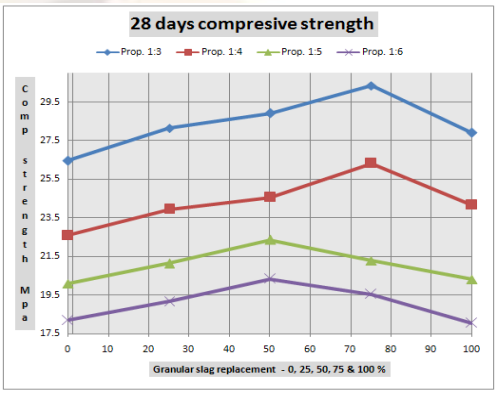

Figure 8 – Mortar compressive strength

Mortar Split Strength

Mortar split tensile strength increased in 1:3 & 1:4 mix proportions at 75% granular slag replacement by 15.97 & 16.0% respectively and in 1:5 & 1: 6 mix proportions the increase was observed 11.56 & 10.29 % at 50% replacement level. The increase in strengths at 100% replacement was noted as 6.08, 7.11 & 5.39% in 1:3, 1:4 & 1:5 mix proportions respectively and in 1:6 it was below 0.59% compare to 0% replacements shown in Figure 9.

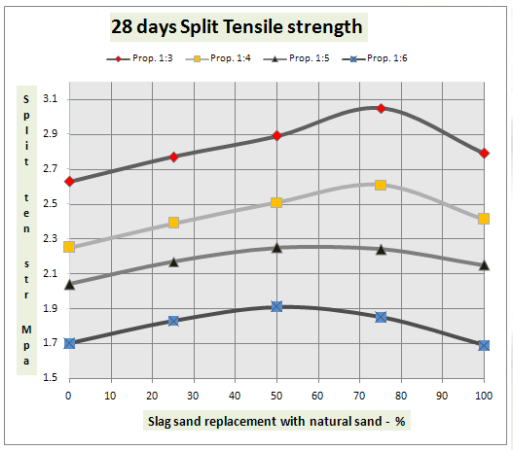

Figure 9 – Mortar split tensile strength

Brick Mortar Joint Crushing strength

The brick mortar crushing strength in 1:3 & 1:4 proportions increased at 75% replacement level by 9.11 & 10.43% respectively compare to 0% replacement on the other hand in 1:5 & 1:6 proportions, the strength was increased at 50% replacement level by 9.11 & 10.43% respectively. It was also observed that in the proportions 1:3, 1:4, the strengths at 100% replacement was found as 6.08, 5.06% and in 1: 5 & 1:6 mix proportions it decreased by 0.78 & 1.5% compared to 0% replacements shown in Figure 10.

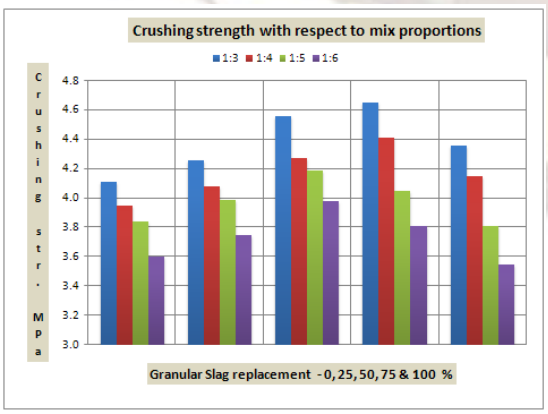

Figure 10 – Mortar joint crushing strength

Brick Mortar Pull/Adhesion Strength

The brick mortar pull or adhesion strength was found the highest in 1:3 & 1:4 mix proportions by 12 to 13% at 75% replacements of natural sand with granular slag at the same time strength improvement was found by 10 to 11% in 1:4 & 1:5 mix proportions. It was also observed that in all the mix proportions the strengths at 100% replacements were higher or equal to standard mixes as shown in Figure 11.

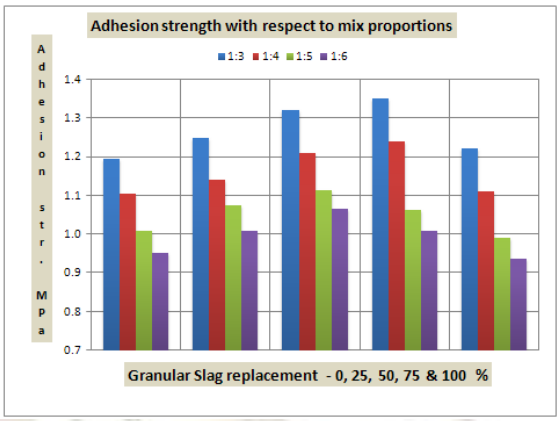

Figure 11 – Mortar joint pull strength

Co-Relations

The co-relations between mortar's compressive/split tensile strength & crushing/pull strength of brick masonry joints for proportions from 1:3 to 1:6 mixes and replacement level of 0,25,50,75, 100 % with slag sand were found out which indicate linear decencies with each other. The equations are given in Table 4 & Figure 12.

Figure 4 – Co-relations between compressive / split & crush / pull strengths

Sr. No.	Co-relation parameters	Compressive/ Split strength	Crushing/ Pull strength
(1:3,1:4,1:5 & 1:6 proportions)			
1	0 % slag replacement	Y = 0.107 x – 0.199, R^2 = 0.978	Y = 0.477 x – 0.79, R^2 = 0.926
2	25 % slag replacement	Y = 0.095 x + 0.105, R^2 = 0.982	Y = 0.401 x – 0.512, R^2 = 0.971
3	50 % slag replacement	Y = 0.088 x + 0.304, R^2 = 0.980	Y = 0.300 x – 0.105, R^2 = 0.962
4	75 % slag replacement	Y = 0.086 x + 0.435, R^2 = 0.944	Y = 0.273 x + 0.001, R^2 = 0.969
5	100 % slag replacement	Y = 0.089 x + 0.420, R^2 = 0.940	Y = 0.270 x + 0.018, R^2 = 0.993

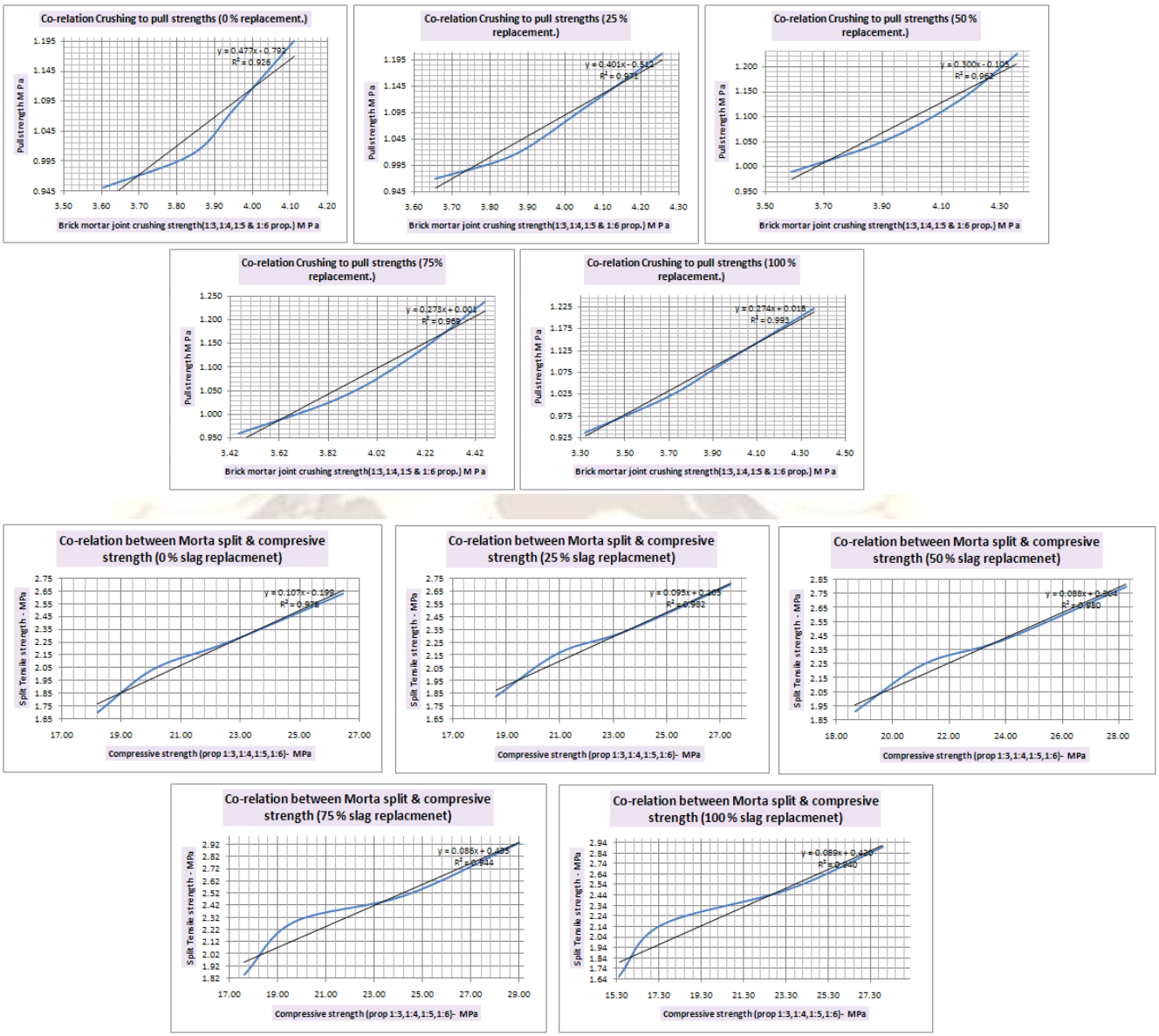

Figure 12 – Co-relations equations between compressive / split & crushing / pull strengths

CONCLUSIONS

The experimental results obtained show that partial substitution of ordinary sand by granular slag gives better results over the verified range from 0, 25, 50, 75 & 100 % replacement. The conclusions are drawn as below,

- In mortar, 50 to 75 % replacement was found favorable to increase the flow properties by 7 % in 1:3 & 1:4 mix proportions however it was lower in 1:5 & 1:6 mix proportions. The 100 % replacement increased flow by 3% 1:3 & 1:4 mix proportions. However 100 % replacement level was not feasible in 1:5 & 1:6 mix proportions since it had reduced the flow by 4 %.
- In general, the range of 25 to 75 % replacement level was found increasing the compressive strength by about 15 & 11 % respectively.
- Mortar split tensile strength increased by about 13 % at 50 to 75 % replacement level in all the mix proportions. It could also be generalized that mortar split tensile strength could be 10 % of mortar compressive strength in all the mixes.
- The replacements of natural sand with granular slag by 50 to 75% improved mortar joint crushing strength by about 10% in all the mix proportions.
- The brick pull/ adhesion strength improved by 10 to 13 % for the replacements from 50 to 75%.
- The co-relation between mortar compressive/split tensile strength & brick

crushing/pull strength shows linear dependencies on each other.

The study concluded that granular could be utilized as alternative construction material for natural sand in masonry & plastering applications either partially or fully.

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