International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 03 Series. IV || March 2019 || PP 01-07

Granite Slurry for Partial Cement Replacement in Concrete: A Review

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Abstract: *The construction industry all around the world is rising towards its new standards. In order to full fill the infrastructural demand of any country, concrete production is necessary. Cement is one of the most important constituent material in concrete and provide binding action to it. Cement production is associated with higher energy consumption and toxic emissions of CO_2 and other harmful gases. It in terms reduces the sustainability of the concrete and affect the environment. Increase in cement production thus affects the environment in a serious way. In order to take care of these factors we will have to reduce the effective cement production by balancing the original cement demands to be full filled by any supplementary cementious material. Years back investigators around the world have investigated the use of granite slurry waste in partial cement replacement in concrete. They reported that replacement of cement by granite slurry waste contribute positively to the mechanical and durability properties of resulting concrete. Granite slurry being a waste material which is hard to dispose also affects the environment. It causes water logging of the area, reduces fertility of nearby soil and affects the growth of plants. Adopting such a granite slurry waste into concrete for cement replacement not only deals with the environmental problems associated with cement production but also provide a strong solutions to the disposal problems of this waste. This overall leads to sustainability in cement-concrete industry. This paper reviews behavior of concrete with partial replacement of cement by granite slurry waste on the basis of available literature.*

Keywords: *concrete, cement composite paste, durability, granite slurry waste, mechanical properties*

Date of Submission: 08-03-2019 Date of acceptance: 28-03-2019

I. Introduction

Concrete is a man-made construction material. Concrete is at 2nd place in the list of most consumed materials in the world followed by water [1]. Cement being a major constituent (5 to 20 percentage) in concrete requires its production in huge quantity to satisfy the rapidly growing infrastructure demands all around the world. Cement production is always associated with great energy consumption, consumption of raw materials and emission of toxic and harmful oxides (nitrogen oxide, sulphur dioxide, carbon monoxide) in the environment [1]. It all affects the environment in a serious way. Demand of concrete (or cement) is growing rapidly day by day. In the year 1950, 200 million tonnes of cement was produced globally which increased to 2.54 billion tonnes in 2006 and it is increasing at present too [2].India being a developing nation requires larger cement production for its infrastructure growth. Indian cement industries produced 217 Mt of cement in 2010 which increases to 280 Mt in 2017 and it will be increased by 6 to 7 percentage in the year 2025. The rapid urbanisation, industrialisation and increasing housing needs in this country are some key reasons behind this increase [3]. This increase in cement production proportionately increases the risk to our environment associated with it.Reduction in CO_2 emissions which are associated with cement production is itself a big challenge for our practices towards sustainability. Cement industries around the world contribute 5% over global manmade CO_2 emissions [1]. Other emissions are also harmful which includes sulphur compounds which are particularly responsible for acid rains, nitrogen oxides produces smog containing small particles which affect human respiratory system, Dust and other particulates also causes problems in the environment. It is therefore highly required for safe environment that, the cement production should be reduced to some safe levels without affecting the actual demand of cement. That can only be possible, by producing blended cement. It will be helpful to reduce actual cement production and hence the problems associated with it.

Granite is a highly demanded dimensional stone. It is used as flooring tiles in buildings. Viewing its architectural values it is also used in gravestones and memorials. Due to its good mechanical properties it is also being used in the engineering applications [10, 11]. In order to use it, it requires sawing, cutting and polishing of the granite blocks. These operations involves the production of an industrial waste material of semi liquid

nature, known as "Granite Slurry". It is very hard to dispose and get rid of this granite slurry waste. If not dispose carefully it affects the growth of plants and crops. It reduces porosity of the surrounding soil, which causes water logging in that area. It reduces the fertility of the soil of the nearby area by increasing its alkalinity and reducing its water absorption. When this slurry gets dry it turns physically into a very fine powder. This powder when comes in contact by breathing causes respiratory problems to the human beings. Under the action of winds it floats and rests on the plants leafs and crops, where it affects their growth. Therefore this granite slurry is not easy to dispose and it is considered as harmful from the environmental point of view.

Years back investigators have investigated the use of granite slurry waste in concrete. Some of them adopted it as an alternative of fine aggregates in concrete and got quite good results of the resulting concrete properties [14-16]. While some of the researches was carried out to investigate the usage of granite slurry in partial replacement of cement. They have found that utilizing this waste, not only improves mechanical properties of the resulting concrete but also changes its durability in a positive manner [4-9]. The problems associated with the production of cement and disposal of granite slurry waste can be solved mutually by implementing such a waste into concrete. Investigators across the globe, utilised granite slurry into concrete and they found it very useful not only for the resulting concrete quality but also for our environment.

It is known to us on the basis of available literature that this waste slurry possesses cementious properties. Which makes it a suitable material to replace cement in concrete partially. This paper reviews the use of granite slurry in concrete for partial cement replacement on the basis of available literature. The effect of various properties of granite slurry on the resulting concrete quality has been discussed with the effect of some other parameters too. Fresh and hardened concrete properties of the granite slurry concrete has also been discussed and presented. Important case studies with proper experimental investigation incorporating granite slurry for partial cement replacement in concrete are included in this review. Concluding remarks has been listed at the end.

II. Properties Of Granite Slurry Concrete

The following are the important features of granite slurry concrete:

1. Cement Composite Paste Properties

Cement while replaced partially with granite slurry, changes its paste properties. The change is dependent on the amount of substitution of cement by granite slurry and the nature of the slurry. Following are some parameters describing the paste properties:

1.1 Consistency

Fineness of granite slurry will not only affect the mechanical properties but it also affects the rheological properties of the mix as observed by Mashaly et al. (2018) [9]. Due to increase in water demand by the high fineness of granite slurry normal consistency increases.

1.2 Porosity and Bulk Density

Density and porosity of the granite slurry concrete is highly influenced by specific gravity and fineness of the granite slurry adopted for cement replacement. Theincreased water demand of the paste increases its porosity [9] and it is attributed by the high fineness of the granite slurry.

Different granite slurry wastes adopted by the investigators for cement replacement in concrete having specific gravity values ranging from 2.17 to 3.01.At the same w/b ratio of 0.5, Chowdary (2015) [7] and Sharma et al. (2016) [4] used the granite waste of specific gravity of 3.01 and 2.17 respectively. It can be observed that higher replacement of granite slurry, 7.5% by weight of cement is achieved by Chowdary (2015) compared over the 5% replacement by weight of cement by Sharma et al. (2016). It is due to the fact that high degree of densification in the concrete can be achieved at higher specific gravity of the granite slurry included in the mix. Similar results can be seen in the study carried out by Mashaly et al. (2018) [9].

1.3 Setting Time

Inclusion of granite slurry as cement substitution accelerated the hydration process due to its fineness which in terms reduces the setting time as observed by many investigators. Deficiency in lime causes cement to set quickly. It was observed that at a lower lime content of granite slurry (3.27%) initial and final setting time for the resulting paste reduced [9]. Mashaly et al. (2018) [9] observed a reduction in the initial and final both setting time which can be correlated with the high aluminium oxide content (11.96 %) of the granite slurry adopted. On the other hand Elmoaty (2013) [6] does not found any change in the setting time because of the lower aluminiumoxidecontent (2.10 %).

1.4 Soundness

There is no change in the expansion of cement paste after granite inclusion for cement replacement [6]. It is due to the very low calcium oxide and magnesium oxide content of the granite slurry adopted by different investigators.

1.5 Paste Content

Increase in paste content with inclusion of the granite slurry for cement substitution can be seen [7]. Which reduces the resistance in the flow of the paste and thus contribute to the workability of the concrete. It is due to the fact that, granite acts as a filler material in cement paste and concrete due to its high fineness.

III. Fresh Concrete Properties

Sharma et al. (2016) [4] and Chowdary (2015) [7] studied the effect of inclusion of granite slurry into concrete over its fresh properties. It was observed that at high w/b ratio of 0.5 the inclusion of granite slurry for cement replacement increases the workability of concrete. The important observation was that at slightly lower w/b ratio the workability was found to be less at the same replacement percentage of cement by granite slurry. Ying et al. (2012) [5], proved that use of water reducers (plasticizers) at low w/b ratios will cater that loss of workability and thus allow higher replacement of cement. They had 40 mm slump value at 40 % rep. of cement by granite slurry which was higher than its respective reference mix. Workability of granite slurry concrete reduces with the reduction in the w/b ratio. Adoption of suitable admixture will cater this slump loss for a constant w/b ratio.

It can be said that the fineness of granite slurry is the governing parameter while we talk about workability. At high w/b ratios fineness increases the paste content [7] and hence the workability increases but at low w/b ratio it will increase the water demand and thus require more water to arrive at same degree of workability.

3. Hardened Concrete Properties

The mechanical properties of the concrete are related to its strength and resistance under different actions of loading. It is very important in order to assure theconcrete quality. Regarding to granite slurry concrete different properties have been investigated by the researchers over time which are as follows:

3.1 Compressive Strength

It is one of the major parameters of our study, as all other mechanical properties are actually a function of compressive strength. Differenttrendshave been observed by the researchers for 28 days compressive strength measurement. Mashaly et al. (2018) [9] and Ying et al. (2012) [5], found that the 28 days compressive strength of concrete with cement substitution by granite slurry reduces for all replacement levels. However the optimum percentages of cement replacement at which the least reduction obtained are somewhat different. In the former study it is 20% while for the later one it is 10%. High fineness of granite slurry adopted by Mashaly et al. (2018) [9] is responsible for this kind of results. While some of the investigators have observed that substitution of cement by granite slurry increases the compressive strength of the concrete up to a limit of substitution [4, 6, 7 and 8]. After that limit of substitution has been reached any further inclusion of granite slurry reduces the compressive strength of granite slurry concrete while compared with respective reference mix. However, that limit of substitution or replacement of cement by granite slurry is different for each of them. The optimum replacement of cement is observed as 5% by Sharma et al. (2016) [4] and Elmoaty (2013) [6], 7.5% by Chowdary (2015) [7], and 10% Kumar et al. (2015) [8]. The lowest w/b ratio of 0.39 along with the use of admixture (plasticizer) allows higher replacement of cement by granite [8].

Investigators have adopted differentwaterbinderratios ranging from 0.39 to 0.5. At lower w/b ratio of 0.4 or 0.39 it is observed that an optimum replacement level of 10% of the cement with granite slurry can be achieved. At the increased w/b ratios of 0.45 and 0.5 it can be seen that replacement percentages of cement by granite slurry decreases and reaches to 5 % to 7.5 %. Sharma et al. (2016) [4], carried out their research work at different w/b ratios of 0.4 and 0.5 under the same experimental conditions. It was found that at w/b ratio of 0.4 they had optimum replacement level of 10% on the other hand at w/b ratio of 0.5 it falls down to 5%.The highest increase in 28 days compressive strength can be seen at a lower w/b ratio of 0.39 and it is about 36.59 % of the respective reference mix. It is attributed by suitable adoption of plasticizer at such a lower w/b ratio. The effect of w/b ratio on compressive strength of the granite slurry concrete can be seen in the study carried out by Sharma et al. (2016) [4]. They have adopted different w/b ratios for the same experimental conditions and grade of concrete. They observed an increase in compressive strength by 15% and 19.2% compared to reference mix at w/b ratio of 0.4 and 0.5 respectively. At high w/b ratio of 0.5 workability of the mix increases which maintains a good integrity and results into a dense matrix of concrete, which is responsible for increase in compressive strength.

Sharma et.al (2016) [4] have alkali content, Na_2O and K_2O content of 6.16% and 4.56% respectively in the granite slurry they have adopted. This is what responsible for their early age strength gain. The same observations have also been recorded by Mashaly et al. (2018) [9] with 4.69% and 3.84% of Na_2O and K_2O respectively in the granite slurry. It was observed that presence of alkali content facilitates the hydration process and thus increase the rateofstrengthgain**.**

Research work carried out by Sharma et al. (2016) [4] and Elmoaty (2013) [6] reported that there is increase in compressive strength of concrete by 19.2% and 4.42% respectively. It is attributed by the higher silicacontent of the granite slurry adopted.

Fineness of the granite slurry is another parameter which affects the mechanical properties of the granite slurry concrete. Fineness of ordinary portland cement, provided by Indian standard specifications should be limited to 2250 cm^2/g (IS 8112: 2013). Investigators have found to adopt granite slurry with varying fineness values ranging from 3420 to 4500 cm^2/g. The addition of granite slurry will influence the actual fineness of the cementious material. Mashaly et al. (2018) [9], carried out their experimental work with granite slurry having fineness value of 4500 cm^2/g. It was observed by them that addition of granite slurry up to 20% replacement of cement acts as a pore filler due to its high fineness, and thus leads to concrete densification. On further addition of granite slurry the specific surface area was found to increase, which in turns demand excess amount of cement as well as water for the mix. This leads to decrease in the concrete compressive strength due to resulting porous microstructure of the mix. The same trend was also observed by Elmoaty (2013) [6], Sharma et al. (2016) [4], Chowdary (2015) [7] etc.

3.2 Tensile Strength

Change in tensile strength is another important observation for granite slurry concrete. The test results obtained by the investigators are satisfying the compressive strength test results [6, 7 and 8]. Strength values tend to increase up to any suitable substation proportions of cement by granite slurry. Beyond which on further inclusion of granite slurry the tensile strength tend to decrease. There is 41.15% increase in tensile strength compared to control mix at 10% substitution of cement by granite slurry as reported by Kumar et al. (2015) [8]. It is due to the cleaver judgement in adoption of lower w/b ratio and at the same time adding plasticizers to maintain the fresh concrete properties. The filler action of granite recover the pores in the concrete microstructure and hence a dense matrix is formed which tend to improve the concrete tensile strength.

3.3. Flexural Strength

Sharma et al. (2016) [4], Chowdary (2015) [7], Kumar et al. (2015) [8] obtained the same trend of flexure strength as they have got for compressive strength of the granite slurry concrete for each of the respective concrete mix. However a decreasing trend it flexural strength also observed at all replacement percentages of cement by granite slurry [9]. The higher water absorption of the fine granite slurry adopted in the respective cement paste leads to poor microstructure formation. Therefore the flexure strength reduces at all replacement levels.

IV. Durability Properties

Concrete prepared with substituting the cement partially with granite slurry should be durable in order to be accepted for structural purposes. Durability of granite slurry concrete has been observed by different investigators with different parameters like corrosion resistance, freeze thaw resistance etc.

4.1. Freeze-thaw Resistance

Mashaly et al. (2018) [9] observed that all of the tested specimens for granite slurry concrete with different amount of granite substitution for cement passes the free thaw resistance test. They observed no sign of cracking or damaging and also no noticeable weight loss for each mix of granite slurry concrete. After subjecting the specimens to 49 freeze thaw cycles it was observed that at 20% partial replacement of cement by granite slurry gives largest compressive strength even when it was compared with control mix. This is attributed by the filler effect of the granite slurry.

4.2. Permeability of Concrete

Ying et al. (2012) [5], investigated the impermeability of the granite slurry concrete at different replacement proportions of cement by granite slurry. It was found by them that fine granite slurry improves the impermeability of the concrete and even at 30% replacement of cement with it results in a better impermeability compared to that of control mix. The use of lower w/b ratio and plasticizer makes the concrete durable.

4.3. Resistance to Sulphate Attack

It is measured in terms of loss of compressive strength. Mashaly et al. (2018) [9], observed that loss in the strength is more when substitution of cement by granite slurry is above 20%. The poor microstructure of the granite slurry concrete beyond this replacement level is truly responsible for the results they have got.

4.4. CorrosionResistance ofConcrete

This test which has been carried out by the Elmoaty (2013) [6] gives an idea of using granite slurry concrete as reinforced cement concrete. The weight loss in steel under the adverse conditions of the test was measured by them. It was found that inclusion of 5% granite slurry with cement substitution gave minimum weigh loss in steel. The filler action of the granite will improve microstructure and hence the durability of the granite slurry concrete.

V. Case Studies

Granite slurry concrete required more investigations in order to be used on field actually. Here we have detailed case studies for concrete incorporating granite slurry for partial cement replacement which can be useful for the future studies.

1. **Case Study-I: "Strength Properties of Granite Slurry Concrete prepared with partial cement replacement"**(Sharma et al., 2016) [4]

In this study systematic experimental investigation has been carried out to explore the use of granite slurry in concrete for partial cement replacement. Ordinary portland cement of grade 43 wasadopted. Different mixes were prepared for M25 grade of concrete with two different w/b ratios of 0.5 and 0.4. Specimens were tested for workability, compressive strength and flexural strength properties. It has been observed that replacement percentages of cement by granite slurry as well as the selection of suitable w/b ratio will affect the strength properties of granite slurry concrete. All the results of specimens prepared with different amount of granite slurry incorporation were compared with that of respective control mix.

Workability of the concrete was tested with slump cone test as per IS: 119-1959. An increase in slump values at w/b ratios of 0.5 & 0.4 could be seen while compared with reference mix values. Compressive strength of the concrete has been evaluated as per IS-516:1959 after 7, 28 and 90 days of curing. At w/b ratio of 0.5, maximum compressive strength was obtained at 5% partial cement replacement by granite slurry for all ages of curing. At w/b ratio of 0.4, maximum strength could be seen at 10% replacement of cement for different intervals of curing. Flexural strength test of the granite slurry concrete specimens has been carried out according to IS-516:1959 with two point load flexural strength test apparatus. After7 and 28 days of curing, at w/b ratio of 0.5 optimum replacement of cement by granite slurry could be 5%. While it is 10% at w/b ratio of 0.4. The increase in concrete strength could be result of improvement in microstructure of concrete by fine graniteslurry. While the reduction in the strength after optimum replacement of cement was because of reduced cement content as cement is partially replaced by granite slurry as reported by the investigators.

Results encourages the use of granite slurry in concrete. Granite slurry concrete have shown good characteristics at 5 % replacement level. Itprovide a source of disposal of granite slurry. The less consumption of CO_2 was estimated due to reduction in demand of cement because a part of it is to be full filled by granite slurry. This concrete is cheaper and more sustainable.

2. **Case Study-II: "Effect of Granite Slurry Incorporation for Partial CementReplacement on Mechanical Properties and Corrosion Resistance of Concrete"**(Elmoaty, 2013) [6]

This study shows the influence of incorporating granite slurry into concrete for cement replacement as well as cement addition on itsmechanical and corrosion resistance properties. Various replacement or addition levels to cement were studied (0%, 5%, 7.5%, 10% and 15%). In this study a high range water reducing admixture was used to maintain a slump value of 140 mm to 180 mm. Ordinary Portland cement was used in the study and a w/c ratio of 0.45 has been adopted. Compressive strength and tensile strength of concrete. Physical properties of modified cement was also observed and reported.

It was found that there is no significant changes in the initial and final setting time and in expansion of cement paste modified with granite dust while compared with control paste. Compressive strength test was carried out for 7, 14, 28 and 56 days for 150 mm cubes of concrete as per the specifications of BS: 1881Part 3. 5% cement replacement by granite slurry is found to be effective and increases the concrete compressive strength. After this level further replacement of cement will reduces the strength. With age of curing there is reduction in compressive strength reduction. Maximum reduction in concrete compressive strength was 10% at the age of 56 days, which can be declined by adopting lower w/c ratio as reported by the investigator. Cement addition was also found to be effective up to 10% and gave maximum compressive strength of concrete cubes. Further addition will cause reduction in the strength. Enhancement in concrete compressive strength were observe to increase with time. Splitting tensile strength of concrete has been investigated following the

specifications of ASTM C 496 on cylindrical specimens of 75 mm diameter and 150 mm length. The optimum replacement and addition to the control cement was found to be 5% and 10% respectively. Replacement or addition beyond this level reduces the concrete tensile strength. These results were satisfying the results of compressive strength test for all ages of curing. Increase in strength values was attributed by the filling effect of fine granite slurry, while the reduction in strength was due to reduction in cement content. A little improvement in concrete porosity could be seen at 5% inclusion of granite slurry as cement replacement or addition.

Corrosion resistance of granite slurry concrete was investigated by accelerated corrosion cell test on cylindrical specimens of 75 mm diameter and 150 mm length with steel bars of 10mm diameter and 200 mm length at the middle of the specimen. Current intensity, time of initial visible crack and weight loss in steel reinforcement was measured. Inclusion of granite slurry up to 5% both as cement addition and replacement was increasing the time of corrosion cracking. Also minimum weight loss in reinforcing steel was observed at 5% and 10% based on inclusion of granite slurry as cement replacement and addition respectively.

Results of the study have shown that incorporation of waste granite slurry into concrete has positive results on the mechanical as well as durability properties of the granite slurry concrete. Inclusion of granite slurry up to an optimum amount will improve the microstructure of the concrete because of its high fineness values.

VI. Concluding Remarks

Utilisation of waste granite slurry in concrete for cement replacement improves the mechanical and durability performance of the concrete. At the same time it gives a better approach towards disposal of granite slurry which is beneficial from environmental point of view. Viewing all the experimental works carried out by different researchers following concluding remarks can be made:

i. Water-binder ratio of the designed concrete mix will affect the replacement level that can be achieved for cement substitution by granite slurry waste. At lower w/b ratio for the specified slump values slightly higher substitution of cement can be achieved.
ii. At high w/b ratio of 0.5 inclusion of granite slurry increases the workability of granite slurry concrete
iii. At lower w/b ratio of 0.3 or 0.4 it becomes necessary to adopt a suitable plasticizer in order to maintain the fresh concrete properties.
iv. At lower w/b ratio of 0.3 or 0.4 adoption of plasticizer with a fine granite slurry resulted in a dense matrix formation in the granite slurry concrete. Which improves the tensile and flexural strength of the concrete. Adoption of plasticizers increases the optimum replacement percentages of cement by granite slurry.
v. Inclusion of the granite slurry increases the water demand of cement paste. It accelerates the hydration process and reduces initial and final setting time of cement paste.
vi. Chemical composition of the granite slurry affects the properties of granite slurry concrete. High silica (SiO_2) content in the granite slurry contribute to the compressive strength of the resulting concrete. Aluminium oxides present in the granite slurry imparts quick setting to the granite slurry concrete and reduces its initial and final setting time. Alkali content in the granite slurry increases the rate of strength gain of the granite slurry concrete.
vii. With the inclusion of granite slurry the compressive strength of the resulting concrete increases initially up to the optimum replacement levels. After that, compressive strength reduces. The optimum replacement percentages are dependent on the properties of granite slurry and w/b ratio of the mix.

viii. Durability of the concrete measured in terms of freeze thaw resistance and sulphate attackand enhances with inclusion of granite slurry for cement substation up to an optimum percentages of replacement. Inclusion of granite slurry improves the impermeability of the granite slurry concrete.
ix. Viewing the concrete corrosion properties, 5% replacement of cement by granite slurry gives good results.

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Gaurav Sharma" Granite Slurry for Partial Cement Replacement in Concrete: A Review" International Journal ofEngineering Science Invention (IJESI), Vol. 08, No. 03, 2019, PP01-07