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Impact on mechanical properties of cement sand mortar containing waste granite powder

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HIGHLIGHTS

- Fine aggregate in cement mortar has been replaced partially by granite waste powder.
- Mechanical properties of cement mortar containing waste granite powder have been studied.
- Results of study have been supported by micro analysis.

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ABSTRACT

Solid waste management is a global challenge. Slurry generated from granite processing industries is one of the major sources of total solid waste production. This paper reports the feasibility of utilizing waste generated from cutting and finishing of granite blocks as a replacement of fine aggregate in mortar mixes. With this in mind, fine aggregate in cement mortar mixes was replaced by waste granite powder in the range of 30–40% by volume. Workability, compressive strength, tensile bond strength, adhesive strength, water absorption, drying shrinkage and ultra-sonic pulse velocity, dynamic modulus of elasticity of all the mortar mixes were studied. It was observed that water requirement reduces by 7 and 3% at 30 and 40% by volume replacement respectively in blended mortars. This lesser water content for the same amount of workability has helped in improving other mechanical properties of such mortars. Compressive strength, tensile bond strength and adhesive strength were increased by 4%, 23% and 23% respectively as compared to those of control mortar in 1:4 mix proportion. Drying shrinkage for blended mortars was comparable to that of the control one. Substitution by waste granite powder also increased the volume of hydrated cement which was confirmed by Fourier-transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD) techniques. Hence it is concluded that such blended mortars perform better than conventional ones and therefore can be safely used for masonry and plaster work.

1. Introduction

Granite is one of the most desired dimension stone available in India for construction projects. It is a type of igneous rock which is formed from slow crystallization of magma present below the earth surface. The major minerals present in granite are quartz and feldspar. India's part in granite production in 2014 was roughly about 45–55 million square meter [1].

Approximate 250–400 tons of granite waste is generated every year from the cutting and finishing of granite block. It is estimated that 30% of the above quantity is lost as dust [2]. This fine granite powder is accumulated in the form of slurry at the cutting and finishing industries engaged in processing of granite blocks [3]. With time, water present in the slurry gets evaporated. The remaining residue of fine granite powder is a type of non-biodegradable industrial waste. The disposal of this waste is a major problem as it creates pollution of air as well as land. Air pollution causes eye infections and asthmatic problems while land pollution includes filling pores of soil which prevent the recharge of ground water and also reduces the soil fertility.

Apart from concrete, mortar also consumes a large amount of fine aggregate for masonry and plastering purposes. This has led to an uncontrolled exploitation of river sand, which in turn leads to its scarcity. As a consequence, there is an immediate need to find an alternative to natural sand due to the huge demand in the construction industries. By understanding the problem of utilization of natural sand in construction, researchers have shown progressive and beneficial effects of waste materials like tire rubber ash [4], limestone [5], fine ceramic [6], blast furnace slag [7], fine sanitary

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ware aggregate [8], fly ash [9] and silica fume [10] in the preparation of mortar.

There are a large number of research works available, where attempts have been made to reduce the granite waste by utilizing it in concrete. When granite powder was used as fine aggregate in concrete, the slump of concrete decreased due to rough and angular texture of granite powder [11]. When the granite powder was used to replace cement in concrete up to 7.5%, mechanical properties i.e. compressive strength, flexural strength and split tensile strength were increased. For 10% substitution, above properties were comparable to the control concrete. Therefore strength required in concrete can be achieved with the 10% substitution of cement by granite powder [12]. With 5% addition or replacement of cement by granite powder in concrete, the corrosion cracking time of concrete was increased [13]. Plastic and drying shrinkage strain in concrete with granite powder was more than that of control concrete [14]. From microstructural aspects, 30% replacement of sand by granite cutting waste in concrete showed maximum calcium silicate hydrate (C-S-H) gel (observed from XRD analysis) and densest matrix of concrete mixture (observed from SEM images) [15]. Concrete mixes prepared with 30% red granite dust, showed superior fresh and mechanical properties and excellent surface finish. [16]. With regard to the durability, concrete with 25% granite cutting waste in place of river sand showed better resistance to carbonation and corrosion for 0.30 w/c [17].

Only a few studies were traceable, where use of granite waste as construction material in production of mortar has been evaluated. One such investigation evaluated granite sludge as a potential replacement for cement. The study concluded that, use of granite sludge up to 10% replacement of cement reduced the expansion due to alkali silica reaction (ASR) by 38% and reduced the penetration of chloride ions by 70% due to the formation of chloroaluminates [18]. Similarly, granite sludge waste was utilized as a structural component (pozzolanic material and filler) and pigment in the production of cement based mortars. Based on laboratory investigation, it was concluded that 10% granite sludge waste by mass can be used in place of cement without any flinch. When used as a filler in mortar, gradual increment of compressive strength was found for up to 100% replacement. After heat treatment, granite sludge waste converted into reddish pigment. This was due to Fe_2O_3 crystallization which provided an extra benefit in preparing coloured mortars with desirable compressive strength [19]. Use of granite dust as an alternative to sand in the production of 1:3 cement mortar proportion has also been evaluated. Using the waste up to 10% replacement as a replacement of sand improved compressive and flexural strength of the mixes. This was due to the ability of the granite waste to act as a filler. However, an increase in water requirement to prepare such mortars was also reported which resulted in higher drying shrinkage. A replacement made above 10% resulted in higher porosity also [20].

From the above literature review it can be said that granite powder can be one of the many suitable options to replace natural sand as a fine aggregate which might have potential to partially replace natural sand in mortar. However properties like tensile bond strength, adhesive strength, ultra-sonic pulse velocity and dynamic modulus of elasticity have not been evaluated. Hence, in the present study attempt has been made to use granite powder by partial replacing conventional river sand in mortar mixes. Additionally effect of river sand grading on optimum utilization of granite powder has been checked. Properties like workability, compressive strength, ultra-sonic pulse velocity, dynamic modulus of elasticity, tensile bond strength, adhesive strength, water absorption and drying shrinkage of granite powder incorporated mortars have been compared with those of mixes made with river sand only. Scanning electron microscope (SEM), Fourier-transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD) were also conducted to detect variation in microstructure and mineral composition of blended mortars. It is believed that the outcome of this experimental study will help to solve the problem of solid waste management faced by granite cutting and finishing industry.

2. Materials and mix proportions

Portland pozzolana cement was used in preparing mortar mixes. Two types of conventional fine aggregate were used: (i) Coarse river sand (CS), conforming to zone-II of IS: 383 [21] Table 9 and (ii) Fine river sand (FS), conforming to IS: 2116-1980 (sand for masonry mortar) [22] & IS: 1542-1992 (sand for plaster) [23]. Granite powder (GP) was obtained from a nearby industrial area. Physical properties like specific gravity, water absorption & bulk density of both sands and granite powder are shown in Table 1. A comparative statement of particle size distribution of fine aggregates is presented in Fig. 1. The median diameter for CS, FS and GS are 0.409 mm, 0.339 mm and 0.189 mm. Figs. 2(a)–(c) represent X-ray diffraction of CS, FS and GP respectively. The major components found in granite powder are quartz and k-feldspar (Orthoclase) at a diffraction angle of 26.68° and 27.95° respectively. The chemical composition of both river sand and granite powder was evaluated using X-ray fluorescence (XRF) technique which is presented in Table 2.

Two series of mix proportions of 1:4 and 1:6 mortar mixes were used for the experimental study. Blended gradation of CS and GP were done such that they satisfied the required gradation of IS: 2116-1980 [22] & IS:1542-1992 [23]. The arrived proportion was 70:30 and 60:40 for CS:GP which suited the required specification. Hence a total of six mixes were prepared. Air dried sand and granite powder were used to prepare mortar mixes. For each series, 3 mixes were prepared which consisted of (i) Control mix with FS (ii) Mix with 70:30 (CS:GP) ratio and (iii) Mix with 60:40 (CS:GP) ratio. The different mix proportions for the mortar are shown in the Table 3.

3. Tests on mortar

3.1. Flow table test

The flow table test was used to fix the water content of mortars to achieve the necessary workability in their fresh state. The test was performed on each mortar mix as per guidelines mentioned in ASTM C 1437 [24]. For each mortar mix, water requirement was expressed in terms of water cement ratio. Flow value for each mortar mix was kept constant in the range of 105 to 115% of base diameter of standard frustum. The mould having top and bottom diameter of 70 and 100 mm respectively and height of 50 mm was filled in two layers by the fresh mortar. Each layer was tamped 20 times. The mould was taken away from the mortar and the flow table was dropped immediately through a height of 12.5 mm, 25 times in 15 s.

3.2. Compressive strength test

The compressive strength test was experimented on 7 and 28 days water cured mortar cubes as per ASTM C 109 [25]. For each selected curing period (7 and 28 days) four cubes of size 50 mm were tested using a compressive strength testing machine and the achieved values were recorded. The load was applied at a uniform rate of 2–6 N/mm^2 per minute on the specimen. The average of the four values was the compressive strength at the selected age.

$$\text{Compressive strength in MPa} = \frac{\text{Load in Newton}}{\text{Area in mm}^2}$$