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Effects of elevated temperature and water quenching on strength and microstructure of mortars with river sand substitutes

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HIGHLIGHTS

- Manufactured sand and granite powder waste have been employed as river sand substitutes.
- Strength properties have been studied at elevated temperatures.
- Effect of water quenching on mechanical properties and micro structure have been evaluated.

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ABSTRACT

The effect of elevated temperature and water quenching on the strength properties and microstructure of mortars containing manufactured sand (MS) and granite powder (GP) waste as river sand (RS) substitutes has been studied. Two different mortar mixtures with 15% GP waste and 100% MS were exposed to 200 °C, 500 °C, 700 °C and 900 °C for 3 h. The residual strength of these specimens was determined after cooling by water soaking or water quenching (WQ). Micro structures of mortar specimens were investigated by XRD, FT-IR and SEM analysis. Test results show that the mortar incorporating 100% MS as RS substitute exhibits the best performance at all the temperature exposures. All mortar specimens show more loss in terms of splitting tensile strength and flexural strength than compressive strength. However all mortar specimens cooled in water show severe strength loss.

1. Introduction

Concrete may be subjected to various effects such as wearing, freezing–thawing, chemical medium, dynamic loads throughout its physical life. One of them is high temperature and fire [1]. The actual behavior of the concrete exposed to high temperatures depends on many environmental factors such as the properties of materials building up the concrete, heating rate, maximum temperature at which it was exposed to and the period of this exposure, cooling method after maximum temperature and loading level at the time of cooling. Concrete generally provides adequate fire resistance for most applications. However, the strength and durability properties of concrete are significantly affected when subjected to elevated temperatures due to chemical and physical changes.

Many countries are witnessing a rapid growth in the construction industry, which involves the use of natural resources for the development of infrastructures [2]. Among the various building materials, river sand (RS) is one of the most commonly used major aggregate materials for building constructions [3]. Worldwide there is a scarcity of RS and hence there is an increase in the consumption of aggregates due to greater demand by the construction industries [4]. However, increase in the demand of river sand, along with restrictions imposed on the exploitation of the river sand, has resulted in search for suitable alternatives. Several alternative sands have been investigated to overcome these challenges [5,6]. Some of the possible alternatives are manufactured sand [MS], copper slag, etc. Among all alternative materials, MS is receiving greater attention these days as a replacement for RS, because it contains larger amount of fines [7].

Among the 32 states in India, Tamilnadu has 45% of total granite reserve. Using different types of cutting method, granite stones are machined from the quarries and the blocks are transported to the nearby processing plants. Then the stones are subjected to industrial

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processing such as sawing and polishing. Finally the processed stones are used for decorative purposes. During this industrial process, the fine granite particles mixed with water becomes a granite colloidal waste. In addition to that, it is a non-biodegradable granite powder (GP) waste that causes pollution and environmental damage. The amount of wastes in different production stages of the granite industry reaches some 20–25% of its global production, meaning millions of tons of colloidal waste per year and disposal of those fine wastes is one of the environmental problems worldwide today. Even though the reutilization of granite wastes has been practiced, the quantity of wastes reutilized in that way is still negligible. The incorporation of marble and granite sawing powder wastes in the production of bricks and tiles is becoming common practice and has been done successfully in many countries [8,9]. Utilization of granite industry waste in concrete production and the effect of granite powder waste on mechanical and durability properties [10] of concrete have been evaluated and documented.

Effect of elevated temperature on the mechanical properties of normal and high strength concrete/mortar [11–15], normal and light weight aggregate concrete [16,17], concretes made with cement substitutes such as silica fume, fly ash, blast furnace slag, pumice, metakaolin and fired clay [18–23] has been studied by researchers. To the best of our knowledge, only a few investigations have been done with MS as a substitute material and GP waste as a filler material in concrete production as river sand substitutes. To date, less work has been under taken to ensure the reliability of such concretes in aggressive environments like fire and elevated temperatures, which need to be investigated thoroughly. Since most of the fire is extinguished by water in a real situation, the effect of water quenching also should be investigated. It was these concerns that prompted to carry out the research on effects of elevated temperature and water quenching on strength and microstructure of mortars with river sand substitutes. The results of XRD, FTIR and SEM have been combined in order to define the changes in the micro structures of mortars subjected to elevated temperatures. We believe that the detailed investigation carried out on the fire performance of mortars made with RS alternatives will be very useful to concrete technology. Vast research on RS substitutes will be useful in the development of standards/specifications and incorporating in the BIS codes will reduce the pressure on using river sand.

1.1. Research significance

Engineered fine aggregate, called “manufactured sand” and Granite sludge with good morphological characteristics as a filler material have been successfully used as river sand alternatives. However there is still a small amount of literature regarding the effect of high temperature on mortars made with such RS substitutes. Most of the fires are quenched by water jets and the study on water quenching will be of significant importance in better understanding the behavior of mortars that contain river sand alternatives. The fire tests not only provide useful information for fire protection and fire investigation but also to fire services using firefighting jets on concrete structures. The findings may also be of interest to architects and structural engineers who are keen to gain a better understanding of the behavior of concrete under fire conditions.

1.2. Materials

Cement: Ordinary Portland cement (OPC) was used in this study. The main properties are given in Table 1.

RS: RS passing through 4.75 mm sieve and having a specific gravity of 2.54 was used in this study. Grain size distribution analysis was carried out on fine aggregate according to IS 383/1970

Table 1
Properties of OPC.

S.No.	Description	Test results	Requirements of IS: 12269-2013
A.	*Chemical requirements*		
1.	$CaO-0.70SO_3$/ $(2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3)$	0.88	0.8–1.02
2.	Al_2O_3/Fe_2O_3	1.21	0.66 Min.
3.	Insoluble residue (%)	1.15	4.00 Max.
4.	Magnesia (%)	1.01	6.00 Max.
5.	Sulfuric anhydride (%)	2.46	3.50 Max.
6.	Loss on ignition (%)	2.96	4.00 Max.
7.	Chlorides (%)	0.005	0.10 Max.
B.	*Physical requirements*		
1.	Fineness (M^2/kg)	310.4	225 Min.
2.	Normal consistency (%)	28.5	
3.	Setting time (Min)		
	Initial	180	30 Min.
	Final	280	600 Max.
4.	Soundness		
	Le-Chat. Expansion (MM)	1.00	10.00 Max.
	Auto clave (%)	0.02	0.80 Max.
5.	Compressive strength (Mpa)		
	3 days ± 1 h	37.3	27 Min.
	7 days ± 2 h	42.7	37 Min.
	28 days ± 4 h	57.0	in.

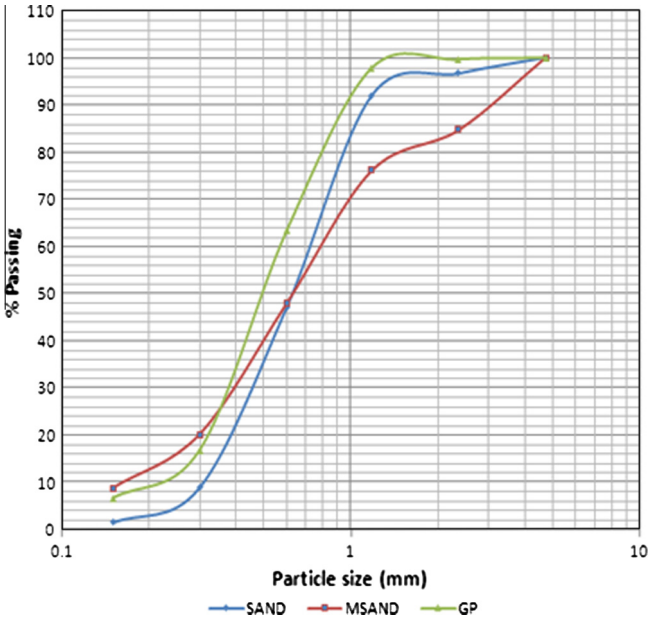

Fig. 1. Grain size distribution analysis on fine aggregate.

[24] and it is shown in Fig. 1. Water absorption of RS is 0.032%. It has silt content of 2%.

MS:MS passing through 4.75 mm sieve and having a specific gravity of 2.57 was used in this study. It has wide range of particles as shown in Fig. 1. Water absorption of MS is 0.68% and it has 2% silt content. The rock used in the present work to produce the manufactured fine aggregate is classified petrologically as granulite and its mineralogical composition consists of alkaline feldspars (15%), plagioclase (12%), quartz (42%), hypersthene (15%) and hornblende (12%) with little amount of Biotite (4%). The rock structure is categorized as isotropic with no foliations and its degree of alteration is very limited. It is, however, characterized by the presence of internal fractures that are within the scale of individual mineral grains. From economic point of view also MS is cheaper than RS.