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Reuse of HDPE and structure of fiber reinforced high strength concrete containing Silica fume and Metakaolin

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ABSTRACT

To address the plastic waste disposal from the municipal solid waste (MSW) and to conserve landfills, there has been interest in the use of recycled and cementitious materials in construction industry. In recent years, utilization of cementatitious materials such as fly ash, silica fume, metakaolin, etc., for the partial replacement of cement is increased because of its pozzolanic reaction with hydrated cement. The municipal solid waste (MSW) generated as 5.03MT per day according to Greater Hyderabad Municipal Corporation (GHMC) reports. This is 0.599gm per head per day. In this study, 3% high densile polyethylene (HDPE) fibers, 7.5% silica fume (SF) and 7.5% metakaolin (MK) were added to control concrete to investigate the improvement in mechanical properties like workability, compressive strength, durability and the structural arrangement. The results are reveals that the increase in compressive strength as 17.7%, 18.2% & 29.3% for the fiber reinforced concrete (FRC), high strength concrete (SMC) and fiber reinforced high strength concrete (FSMC) respectively when compared with control concrete. The laboratory tests XRD, EDS and SEM are conducted for four selected concrete specimens and these results and images disclose that the presence of SF and MK changed the concrete's microstructure, aggregate paste interface and pore size distribution which enhances the concrete strength, workability and durability. The reuse of plastic waste in concrete for laying of cement road is economical and durable.

Keywords: MSW, silica fume, metakaolin, pozzolana, HDPE, EDS, XRD, SEM.

1. INTRODUCTION

Due to the demand from the construction industry, the development of high strength concretes has increased considerably. To reduce the consumption of cement, the cementatitious materials demand such as metakaolin, silica fume, fly ash, slag, etc. as supplementary for replacement of cement has been increased. By addition of pozzolanic materials to the concrete, the various properties viz., workability, durability, strength, resistance to cracks and permeability can be improved. The use of mineral admixtures in concrete leads to increased water demand. SF & MK are very reactive pozzolanic materials, when used in concrete due to its fine particles, large surface area and the high silicon dioxide content. The chemical reaction between SF, MK and portlandite [$Ca(OH)_2$] stimulates formation of a calcium silicate hydrate (C-S-H) gel. Sonicated silica fume exhibits higher reactivity, associated with increased consumption of portlandite during curing, relative to pastes including densified silica fume. This leads to formation of a C-S-H type product with a structure of longer chain length and increased silicon substitution by aluminum and lower Ca:Si ratio than systems including densified silica fume. These structural differences might lead to an improved durability of these materials in the long-term, given that a more stable binding phase is formed (Erich D Rodriguez et. al., 2012). Replacing cement with MK was found to be remarkably efficient to prevent excessive reduction in compressive strength due to sulfate attack, especially at 20% replacement level (Erhan Guneyisi et. al., 2010). The data show that MK reacts rapidly with newly forming CH, leading to a lower CH content from one day of age and older (even beyond 14 days) as compared to control pastes. This is critical to strength and durability, as CH is both mechanically weaker and more susceptible to chemical leaching than C-S-H and other hydration compounds. CH also participates in potentially deleterious sulfate attack reactions (Justice J M et. al., 2007). Mortars, prepared with the SF but mixed without a super plasticizer, did not indicate the presence of any SF coating around the sand grains. Strength increase is also provided by a reduction in the calcium hydroxide content due to its pozzolanic reaction with SF. Amorphous silica made the calcium silicate hydrate microstructure denser and also increased the amount of isolated nm-sized pores. Many of the macroscopic properties of amorphous silica-concrete can be explained by its microstructure and phase properties (Amitava Roy et. al., 2006). The addition of reinforcement in the ultra high performance fiber reinforced concrete layer is the most efficient way to increase the resistance of composite elements. However, this strengthening of the tension chord leads to a reduction in rotation capacity of the cross section, which should be verified in the case of statically indeterminate systems (Katrin Habel et. al., 2006). The micro structural investigation showed that using 15% SF or 15% Rice Husk Ash (optimum dosage) as a partial replacement of cement by weight in the case of concrete led to an increase in concrete densifications and all properties (Sakr K, 2006). Steel microfibers, added to the cement-based matrix, did improve the flexural behavior of reinforced beams in terms of strength and stiffness with enhanced crack bridging leading to a reduction of the structural size effect. Steel microfibers improve load-bearing capacity as is seen when the behavior of very high performance concrete industrial beams with and without fibers are compared. After the point of crack onset, the fiber-reinforced concrete structure is more rigid and the maximum load increases (Meda A et. al., 2003). The incorporation of metakaolin, silica fume and slag into concrete can prompt, both the strength and modulus of elasticity development of a young concrete. Among them, metakaolin shows the best enhancement on the mechanical properties of young concrete (Xianyu Jin et. al., 2003). The objective of this study was to verify the effect of SF, MK & HDPE fibers on the compressive strength of concrete and the structure of concrete at microstructure level. How does the plastic waste from MSW to be utilized in concrete without loss of its characteristic properties. The XRD & EDS results and SEM images for control concrete, fiber reinforced concrete, high strength concrete and fiber reinforced high strength concrete mixes are presented and discussed in this study.

2. EXPERIMENTAL PROGRAM

Materials and Mix Design

The ingredients used for control concrete were cement, fine aggregate, coarse aggregate and water. The admixtures SF, MK and HDPE fibers are added to control concrete for further study on properties of concrete. The cement, coarse and fine aggregates were collected from locally available sources and confirmed to BIS standards. The mix design was followed by IS Code method to produce the concrete compressive strength of grade M40 at 28 days without segregation and bleeding at the time of mixing. The water binder ratio was selected as 0.40 and maintained constant for all mixes. When the MK replacement increased from 5.1 to 19.9%, the compressive strength of samples was increased by nearly 20%. The results showed that by using high MK replacement, low water-to-binder ratio and high binder content, the compressive strength can be maximized in the samples (Ahmed A A et. al., 2014). Partial replacement of cement was done to the control concrete with 7.5% SF and 7.5% MK by mass of cement to made high strength concrete (SMC). The fibers are added to concrete by 3% of volume of concrete to made fiber reinforced concrete (FRC). The mix proportions for selected concretes are presented in Table 1.

Table 1 Mix Proportions for the M40 Grade Concretes

Materials	Control Concrete	Fiber Reinforced Concrete (FRC)	High Strength Concrete (SMC)	Fiber Reinforced High Strength Concrete (FSMC)
Water binder ratio	0.40	0.40	0.40	0.40
Cement, kg/m^3	450	450	450	450
Fine aggregate, kg/m^3	635	635	635	635
Coarse aggregate, kg/m^3	1156	1156	1156	1156
Water, kg/m^3	165	165	165	165
HDPE fibers, kg/m^3	---	2.878	---	2.878
Silica fume, kg/m^3	---	---	33.75	33.75
Metakaolin, kg/m^3	---	---	33.75	33.75

Table 2

Energy Dispersive Spectroscopy of (a) Control Concrete (b) Fiber Reinforced Concrete (c) High Strength Concrete and (d) Fiber Reinforced High Strength Concrete

(a)	Element	Weight %	Atomic %
	O K	65.97	81.40
	Mg K	0.43	0.35
	Al K	1.20	0.88
	Si K	6.95	4.89
	S K	0.51	0.32
	Ca K	24.10	11.87
	Fe K	0.83	0.29
	Totals	100.00	

(b)	Element	Weight %	Atomic %
	O K	59.75	76.46
	Mg K	0.64	0.54
	Al K	1.92	1.46
	Si K	10.94	7.97
	S K	0.70	0.45
	Ca K	24.77	12.65
	Fe K	1.29	0.47
	Totals	100.00	

(c)	Element	Weight %	Atomic %
	O K	59.44	73.15
	Na K	3.97	3.40
	Mg K	0.22	0.18
	Al K	5.75	4.20
	Si K	19.09	13.38
	S K	0.23	0.14
	Ca K	11.29	5.55
	Totals	100.00	

(d)	Element	Weight %	Atomic %
	O K	63.12	78.92
	Mg K	0.49	0.40
	Al K	2.30	1.71
	Si K	9.66	6.88
	S K	0.51	0.32
	Ca K	22.55	11.23
	Fe K	1.22	0.44
	K K	0.20	0.10
	Totals	100.00	

Sample Preparation and Tests

The concrete making has been carried out according to BIS. The specimens of cube of side 150mm were prepared after testing the fresh concrete properties. After 24 hours the samples were demoulded from steel moulds and cured in water for a period of 28 days. The compressive strength test was performed on 51 samples. The powder samples are prepared to investigate EDS and XRD. The cubes of 1cm side were arranged for SEM tests. All the test results are recorded and discussed in this paper.

Municipal Solid Waste

According to report of Greater Hyderabad Municipal Corporation (GHMC), the toal municipal solid waste (MSW) generated was 5030 MT / day in the year 2014. The percapita production of MSW per day in twin cities of Hyderabad and Secundrabad is approximately 0.599 grams. This is a big challenge to GHMC for safe disposal. In this plastic waste, the production and its rate of accumulation is high.

Energy Disperssive Spectoscopy

The chemical composition of powder samples were examined by EDS test. All the EDS observations of four concretes were presented in Table 2. The reaction of SF & MK with calcium hydroxide (CH) yields a product similar to the gel-like calcium silicate hydrate C-S-H obtained from cement.

X-Ray Diffraction

The mineralogical analysis of powder specimens was completed by XRD test. The outcomes of four concretes are revealed in Fig. 1. The 2 theta values from 0^0 to 80^0 are taken on X-axis and the intensity from 0 to 300 are represented on Y-axis in Fig. 1. More number of peaks was observed for control concrete in Fig. 1 (a). The ettringite and portlandite peaks are not recognized in high strength concrete which mean the mineral admixture i.e. SF and MK reacted with cement greatly. From XRD studies more concentration of C-S-H gel and less quantity of portlandite may be responsible for more strength of concrete by the presence of SF & MK.

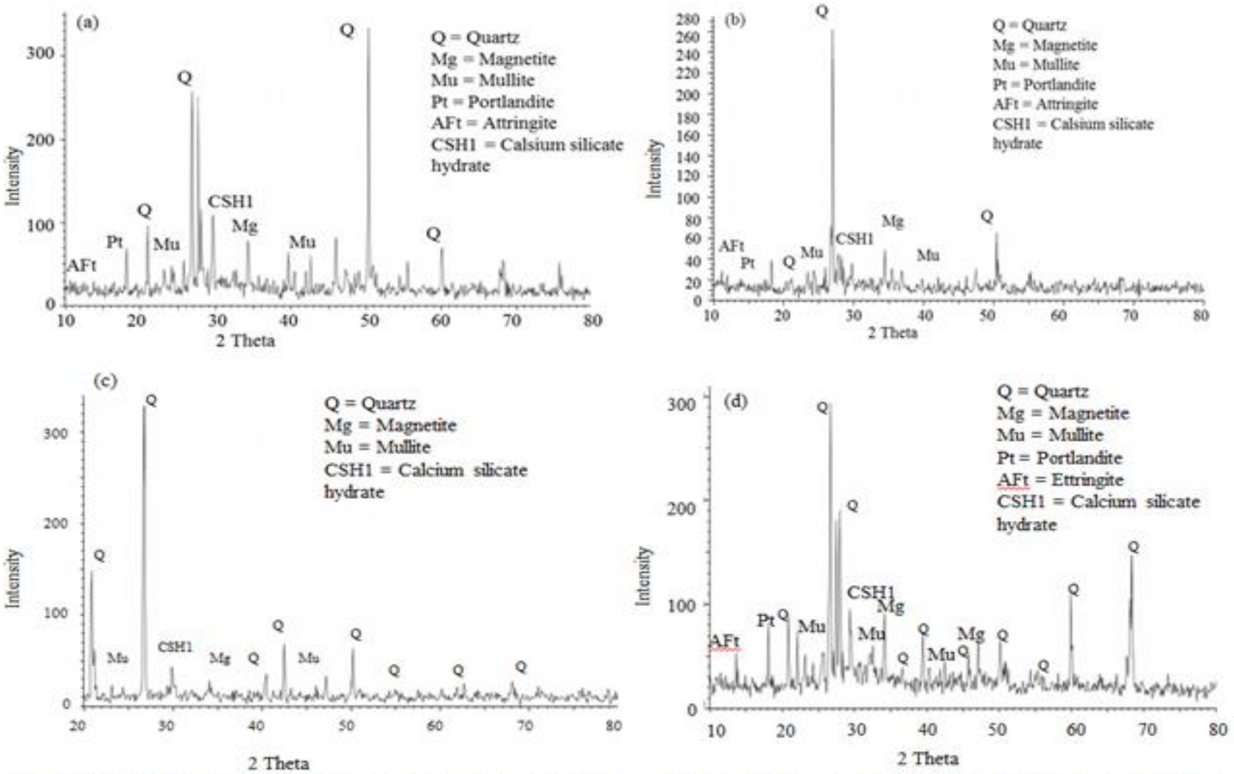

Fig. 1. X-ray diffraction analysis of (a) control concrete (b) fiberreinforced concrete (c) high strength concrete and (d) fiberreinforced high strength concrete

Scanning Electron Microscopy

The morphological analysis of three concretes was finished by SEM and the images are exposed in Fig. 2 & 3. The SM-concrete also appeared to have a high amount of ettringite from Fig. 2. The high specific surface area of the SF & MK has to accelerate the reaction for the high strength concrete when compared with control concrete. The SEM image reveals better bonding among silica fume and metakaolin particles from Fig. 2. The formation of ettringite as evident from the XRD was verified by the SEM images from Fig. 1 & 2. The SEM images Fig. 2 & 3 also explains that the formation of gypsum and ettringite is much reduced due to the pozzolanic reaction of SF &MK. From the corresponding EDS spectrum analysis, it can be perceived that the silica content of blended concrete with MK is greater than that of unblended concrete.

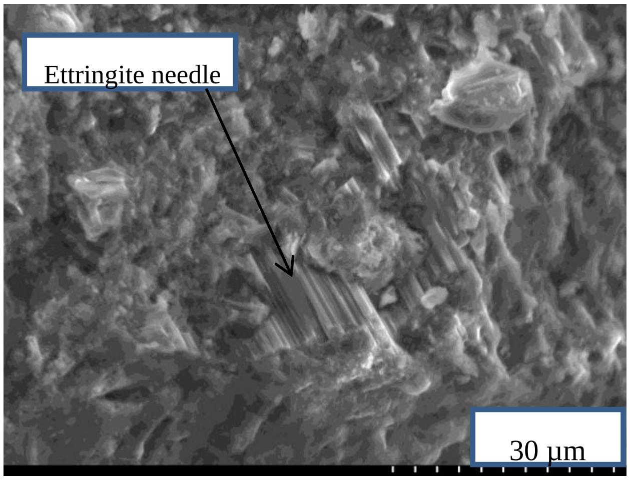

Figure 2. Scanning electron microscopy images of fiber reinforced high strength SFMK-concrete (15.0kV; x1500 magnification; 30µm)

The higher silica content observed in the MK mix indicates that a good pozzolanic reaction and synergic effect has occurred in the Mk blended concrete (Kannan V et. al., 2016).

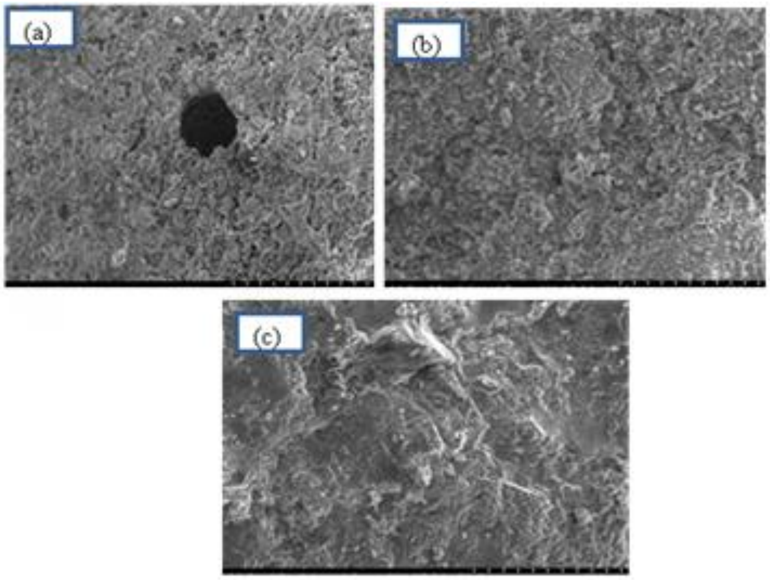

Figure 3

Scanning Electron Microscopy images of (a) control concrete (15.0 kv; x230 magnification; 200µm), (b) fiber reinforced concrete (15.0 kv; x230 magnification; 200µm), (c) fiber reinforced high strength SFMK-concrete (15.0 kv; x230 magnification; 200µm)

Application

The plastic waste should be divided from MSW and cleaned from debris. It will be made as fibers or strips to use in concrete and maintained a constant aspect ratio. The fibers required for one cubic meter of concrete is 1.65kg. The concrete required for one kilometer of cement road is 1800m^3. Total estimated quantity of fibers required or laying one kilometer of cement road is 2.97MT. This reduces the consumption of cement and cost of road per kilometer.

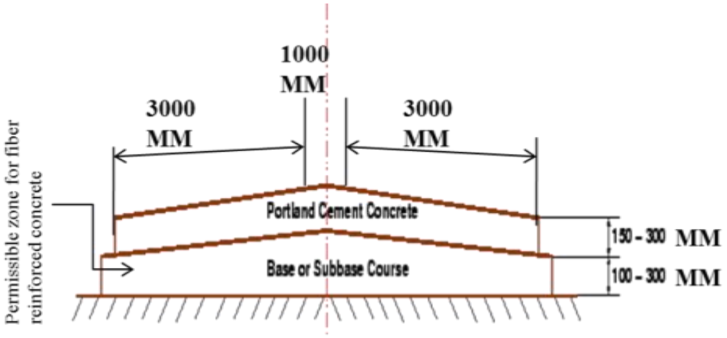

Figure 4

Cross section of cement road

Table 3 Compressive Strength of M40 Grade Concretes

Type	Load in kN	Compressive Strength in N/mm^2	Average Compressive Strength in N/mm^2	% of Improvement in Compressive Strength
Control Concrete	1005	44.67	44.2	----
	986	43.82		
	993	44.13		
Fiber Reinforced Concrete	1194	53.07	52.0	17.7
	1158	51.47		
	1161	51.6		
High Strength Concrete	1201	53.38	52.3	18.2
	1187	52.76		
	1139	50.62		
Fiber Reinforced High Strength Concrete	1285	57.11	57.2	29.3
	1278	56.80		
	1296	57.60		

3. RESULTS AND DISCUSSIONS

The compressive strength results of four concretes were presented in Table 3. The compressive strength of fiber reinforced concrete, high strength concrete and fiber reinforced high strength concrete are 17.7%, 18.2% and 29.3% respectively compared to control concrete. These observations reveals that the significant improvement in strength of concrete. The innovative use of recycled plastics as fiber/strip reinforcement of pavement layers may be a promising concept in terms of both environmental and economic considerations. Plastic strips were obtained from recycled high density polyethylene (HDPE) like that found in milk or water containers collected from the cities (Khaled Sobhan et. al., 2003). From the SEM image in Fig. 3(a), it can be noticed that the control concrete sample consisted of irregular particles with micro pores due to gypsum and ettringite in the surface pores. This may be the reason for its poor strength and durability compared to other selected concretes. Due to the addition of high Pozzolanic mineral admixtures added to concrete leads to a more discontinuous and less permeable pore structure. Thus, the Pozzolanic reaction with CH occurs more quickly. Although SF & MK are known to increases its mechanical performance and improvement in durability properties in cementatitious materials. As discussed previously, concrete containing SF & MK displays very high compressive strength after cured. Steam cured silica fume concrete can achieve the target minimum compressive strengths, as per specifications. Most steam cured specimens reached the 28 day target strength for the selected mixes. All steam cured samples continued to gain in strength with time. At 365 days of age, the samples displayed significantly higher compressive strengths than the 28 day strength (Yazdani N et. al., 2008). In the initial mix, enormous agglomerates of SF & MK were seen with the naked eye. These can be easily known by their white colour and irregular shape. The porous regions were filled with a fine grained material, which appeared like as SF & MK agglomerates. The filling of void spaces by ettringite needles makes the concrete denser, which increases the strength of concrete. The reduction of calcium hydroxide and the increase of calcium silicate hydrate (C-S-H) gel in the cement matrix results from the pozzolanic reaction of SF & MK. The microstructure of the high strength concrete exhibits a homogeneous, compact and uniform structure. The separated plastic waste from MSW makes into fibers or strips to use in mass concrete structures. This will contribute at some extent to reduce the environmental pollution by plastic waste. The reuse of plastic waste as fibers in mass constructions such as bridges, fly over's, concrete pavements, etc. is economical and durable.

4. CONCLUSION

Based on the experimental results and images following conclusions are drawn for the structure of fiber reinforced high strength concrete containing silica fume and metakaolin:

1. The enhanced compressive strength of fiber reinforced concrete, high strength concrete and fiber reinforced high strength concrete is 17.7%, 18.2% and 29.3% when compared with control concrete.
2. The addition of pozzolanic materials to cement increases its mechanical strength and durability as compared to control concrete, because of the interface reinforcement. The physical action of the pozzolana provides a denser, more homogeneous and uniform structure.
3. The reuse of 3% HDPE fibers from MSW into concrete will reduce the plastic pollution effect significantly.
4. The reuses of plastic waste as fibers into concrete make the construction of cement road more economical.

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