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EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF NANO GRAPHITE PLATELETS ON THE COMPRESSIVE STRENGTH OF CONCRETE WITH RECYCLED PLASTIC AGGREGATES

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Abstract- The rapid increase in industrialization, population, and modern life style has significantly increased the rate of waste production. As a result of technological advancement and up gradation of technological innovations, the rate of obsolescence in the electronic equipment's has also increased making it one of the fastest growing waste streams in the world. The current annual production rate of Electronic or E-waste is 3-4% in the world. E-waste will be increased approximately to 55 million tons per year by 2025. This E-waste significantly damages the environment because of its non-biodegradable nature. In order to diminish this problem one of the ways is to utilize this E-waste in the concrete production. Past works have used the E-waste plastic as a raw material for production of plastic aggregate to be used as a substitute for natural aggregates. However, the results have shown the plastic aggregate reduces the compressive strength of resulting concrete. In order to enhance the strength properties, different dosages of nano graphite platelets (NGPs) (i.e. 1, 3 and 5%) have been introduced into concrete with replacement of 25% coarse aggregates by plastic aggregates. Dispersion test is carried and a ratio of 0.6:1 (surfactant/NGPs) is found to yield maximum dispersion. NGPs are nanofillers which significantly improve the density and hardness of the cementitious composite due to reduction in porosity and reinforcement in microstructure. The specimen that contained 25% (by volume) of E-waste as an aggregate, and 5% of NGPs (by weight of cement) was proved effective in increasing compressive strength by 13.56%.

Keywords- E-waste, nano graphite platelets, dispersion, compressive strength.

1 Introduction

Concrete is considered to be the second most extensively utilized material in construction industry. This can be attributed to its properties, accessibility to its raw materials, low price in conjunction with increasing industrialization and urbanization. This led to increasing natural rocks exploitation which resulted in deterioration of the landscape and escalation in environmental pollution. The rapid increase in industrialization, urbanization and population growth significantly increased the amount of waste generation. The use of modern electrical and electronic appliances turns out to be an essential part of our everyday life enabling us with more convenient, secure, comfortable, easy and swift procurement. As a result of technological advancement and continuous up gradation of technological products, the rate of waste generation in the electrical and electronic equipment also increased, making it one of the fastest increasing waste streams in the world. E-waste significantly damages the environment and its disposal process is relatively more difficult compared to other waste streams. To prevent the environment from the adverse and hazardous effect of E-waste, proper utilization is required along with its disposal. In order to tackle this problem one of the ways is to utilize this waste in concrete production. To minimize the adverse impacts on environment and diminishment of natural resources [1, 2], the preservation of raw materials needs to be emphasized. In concrete, coarse aggregates occupy 65-70% of volume. Large scale use of concrete ingredients especially use of coarse aggregates from rocks causes depletion of natural resources thus welcoming disasters in the form of global warming, land sliding and depletion of ozone layer. Nowadays, many countries around the globe are facing a deficiency of natural resources, and depend on the imports to meet their needs[3]. Efforts are required to take important steps in order to save the nature without compromising on the overall performance of concrete. Various attempts has been carried out in the past with the ambition of substituting natural aggregate with recycled aggregate[3, 4]. Therefore, several other alternatives in concrete to natural aggregates like demolition waste, plastic waste, paper etc. has gained momentum.

Zeeshan et al. [5] conducted an extensive investigation by utilizing manufactured E-waste as a partial substitute of coarse aggregate. The substitution ratio of E-waste aggregate was 10 to 20%. It was revealed that by substituting coarse aggregate by 10 and 20% of E-waste, the mechanical properties decreased while an improvement in durability and workability properties were reported. Needhidasan et al. [6] studied the effect of grinded E-waste on the concrete performance. The range of substitution ratio used was 0 to 20% of coarse aggregate by volume. It was reported that the decrement in compressive and flexural strength occurs with the increments of E-waste but the tensile strength increased. Also, the utilization of E-waste plastic in concrete production not only prevented the environmental degradation but also reduced the cost and unit weight of concrete. M.Chougan et al. [7] studied the variation of density, microstructure, compressive strength, flexural strength and permeability properties of concrete with different commercial nano graphite content (i.e. 0.01, 0.1 and 0.2%) and found that there is significant increase in mechanical characteristics and density up to 30% and 16%, respectively and a significant decrease in permeability. W.Meng el al.[8] investigated the effect of different nanomaterials like carbon nanofibers (CNFs) and graphite nanoplatelets (GNPs) on the mechanical performance of ultra-high performance concrete (UHPC). The dosage of nanomaterials ranged from 0 to 0.3% and it was found that the compressive strength increases from 5 MPa to 8 MPa. It was also reported that 59%, 276% and 56% enhancement was observed in flexural strength, toughness and tensile strength, respectively. However, no work has been reported to date where nano materials are used to enhance the strength properties of concrete with plastic aggregates. In this research, an attempt is made to enhance the compressive strength properties of E-waste incorporated concrete with the addition of nano graphite platelets (NGPs).

2 Materials and Experiments

Ordinary Portland cement (OPC) Type-I, meeting the guidelines as per ASTMC150 was utilized as a binder. Table 1 indicates different characteristic of Type-1 cement. Commonly used tap water with a PH range between 6.5 and 7 is used. Fine aggregate utilized in this research was "Lawrence Pur sand" with maximum particle size of 4.75mm in compliance with ASTM C566. Coarse aggregate utilized was obtained from Margalla brand in Taxila, Pakistan with maximum particle size of 20mm. Properly manufactured E-waste plastic aggregate by heating process of required shape and size comparable to coarse aggregate was utilized in this research work as shown in Figure 1(a). Table 3 indicates the physical properties of fine and coarse aggregates as well as manufactured E-waste plastic aggregates. Nano graphite platelets (NGPs) were commercially purchased in powder form and its elemental composition obtained from EDX spectroscopy is listed in Table 2. The surface texture and morphology of NGPs were determined using SEM which indicates that the NGPs have rough texture and irregular shape as shown in Figure. 1(b). Acacia gum (AG) was utilized as a natural surfactant for effective dispersion of NGPs.

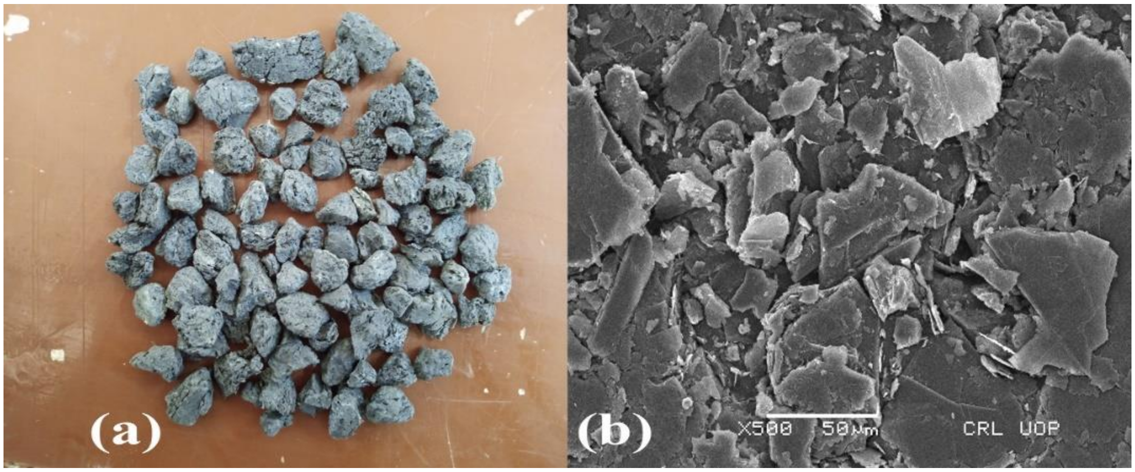

Figure 1: (a) Manufactured E-waste aggregate and (b) SEM micrograph of NGPs

Table 1-Features of OPC

Chemical composition	**Content (%)**
CaO	63.58
SiO_2	21.9
Al_2o_3	5.1
Fe_2O_3	4.1
MgO	2.56
SO_3	2.74
Na_2O	0.23
K_2O	0.88
Ignition loss	0.63

Table 2-Elemental Detail of NGPs

Elements	**Nano graphite platelets (NGPs)**	
	Weight (%)	**Atomic (%)**
C	83.77	90.45
O	7.83	6.35
Mg	0.62	0.33
Al	0.64	0.31
Si	2.97	1.37
S	0.32	0.13
Ca	1.81	0.59
Fe	2.03	0.47
Total	100	100

Table 3-Physical properties of fine and coarse aggregates, and manufactured E-waste aggregates

Property	**Coarse Aggregate**	**E-waste aggregate**	**Fine Aggregate**
Max. nominal size(mm)	20	19	4.75
Min. nominal size (mm)	4.74	4.75	0.074
Specific Gravity	2.71	1.21	2.78
SSD water Absorption (%)	1.08	0	0.5
Color	Dark	Black brown	Dark
Shape	Angular	Angular	_
Aggregate impact value (%)	25.43	8.108	NIL
Aggregate Crushing value	27.42	1.3	NIL
Fineness Modulus	Nil	Nil	2.27
Bulk Density(lb./ft^3)	94.05	30.43	100

1.1 Concrete mix proportions

In this research, M25 grade concrete was followed and the mix ratio was 1:2.14:3.08[9]. The maximum size of coarse and fine aggregate was 20 and 4.75 mm, respectively and water cement ratio was kept at 0.49. In this research, about 25% of E-waste aggregate by volume of coarse aggregate was incorporated in concrete along with different percentages of nano graphite platelets (NPGs) (i.e., 0%, 1%, 3% and 5%). Tilting drum revolving with speed of 35rev/min was utilized for concrete mix preparation. Five different concrete mixes with one control mix and the other four of E-waste incorporated concrete with different percentages of NGPs were prepared. Each E-waste incorporated concrete mix contained 25% of E-waste by volume of coarse aggregate with 0, 1, 3 and 5 % NGPs respectively. The mixing of concrete was done in three stages. Firstly, the NGPs along with specified amount of acacia gum (AG) was dispersed in water with the help of ultra sonicator. Secondly, the coarse, fine and E-waste aggregates were mixed along with 75% of total water (containing dispersed NGPs) for four minutes. Thirdly, the remaining 25% of water with cement were also added and mixed for the next four minutes. 30 cylinders of dimension (150mmx300mm) were prepared and tested at 7 and 28 days. Table 4 indicates the details of concrete mixes.

Table 4-Details of concrete mix proportions

Mix ID	Cement (Kg/m^3)	Water (Kg/m^3)	W/C	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	E-waste (kg/m^3)	NGPs (kg/m^3)
Control Mix	367.34	180	0.49	789	1133.3	___	___
E.W25%NGP0%	367.34	180	0.49	789	850.0	126.51	___
E.W25%NGP1%	367.34	180	0.49	789	850.0	126.51	3.67
E.W25%NGP3%	367.34	180	0.49	789	850.0	126.51	11.02
E.W25%NGP5%	367.34	180	0.49	789	850.0	126.51	18.37

3 Results and Discussion

3.1 Dispersion of NGPs

NGPs consist of graphite which is closely packed and has an affinity to agglomerate because of its large surface area and fine particle size. The Van der Waals forces resist its dispersion into the cementitious matrix. Therefore, it is needed to homogeneously disperse NGPs in cementitious composites. For the dispersion of NGPs, the use of natural surfactant or chemicals with mechanical sonication is required in order to reduce the impact of powerful Van der Waal forces [10]. In this research, a natural surfactant i.e., Acacia gum (AG) was utilized to disperse NGPs effectively by breaking the Van der Waals interactions among NGPs [11, 12]. Initially, NGPs to surfactant ratios from 1:0 to 1:1 was chosen. To obtain dispersed solution, the surfactant-ultrasonication method was used and then it is further diluted to the amount of water required for concrete preparation. After that a prototypical sample was collected, to examine the effectiveness of dispersion. The absorbance of dispersed aqueous solution is generally examined at 500nm (whereas 500nm is the wavelength to be adjusted on UV spectroscopy apparatus), which remains least affected at the ambient conditions [11]. The absorbance of dispersed aqueous solution for each ratio of NGPs/surfactant (1:0 to 1:1) with increment of 0.2 was examined. Finally, Graph is plotted between Surfactant/NGPs ratios and absorbance at each corresponding ratio. The results indicated that the ratio of 0.6:1 (surfactant**:** NGPs) shows maximum absorption and is optimum to obtain uniform dispersion aided with 45 min of mechanical sonication as given in Figure 2.

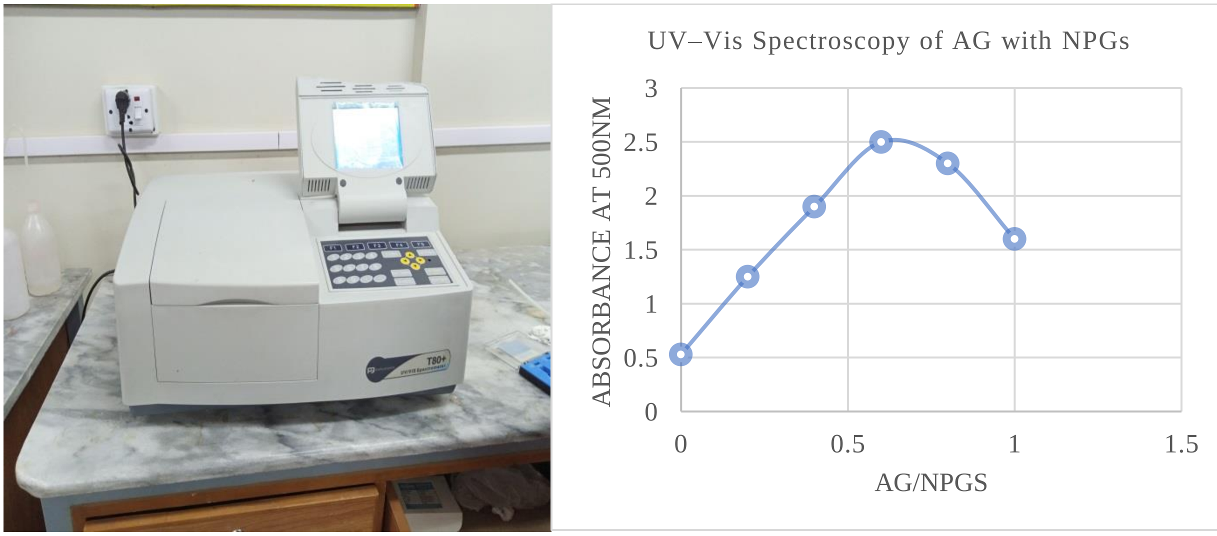

Figure 2: UV-Vis Spectroscopy of AG with NGPs

3.2 Compressive strength

In the design of reinforced cement concrete (RCC) structures, concrete compressive strength is considered as one of the fundamental property. In the present study, cylindrical compressive strength of concrete containing E-waste is determined in compliance with ASTM C39 [13]. Before testing, both ends of the cylinder were provided with rubber pads to prevent any surface irregularity to effect the result as well as the ends to be orthogonal to the sides of specimen as shown in Figure 3. Compressive strength was measured with the help of universal testing machine (UTM) having 1000 kN capacity. Figure 4(a) reported the results of cylindrical compressive strength at 7- and 28-days curing. The results show that the compressive strength of E-waste incorporated concrete significantly declines which is in compliance with the past works [14, 15]. This reduction in strength is because of the smooth texture of E-waste aggregates thereby yielding a weak adhesion with the cement paste. Also, because of the hydrophobic nature of plastic aggregate, it may prevent the intrusion of requisite quantity of water during curing which is necessary for the process of hydration. Another reason of strength decrement may be because of low water absorption/non-absorbent behavior of E-waste aggregates thereby causing excess content of water in concrete mixes. Besides, E-waste aggregates have less unit weight, density, strength and rigidity in contrast to natural coarse aggregates thereby generating a high stress region facilitating the spread of damage which may be the cause of strength decrement [16, 17]. The results shown in Figure 4(a**)** also reported that by incorporating NGPs in concrete containing plastic aggregate, increase in compressive strength was observed as compared to E-waste concrete without NGPs. This increase in compressive strength is a result of the inclusion of NGPs which strengthened the composites at nano level thereby resulting in an improvement in the strength. Previous studies mentioned that incorporating nanofillers (GNPs, GONPs, NGPs, nG etc.) in cementitious composites significantly improve their density and hardness due to the reduction in porosity and reinforcement in microstructure of cementitious composites[7, 18].

The results reported that the strength of concrete comprising 25% partial substitution of coarse aggregate via E-waste aggregate decreased by 26.3% after 28 days curing compared to control samples. Also, the results reported that compressive strength of E-waste concrete containing 1, 3 and 5% NGPs has been improved compared to E-waste concrete without NGPs. Figure 4 (a) and (b) indicates the assessment in compressive strength and the rate of strength gain at various curing ages. It has been observed that the regular rise in compressive strength occur with increasing dosage of NGPs in the E-waste concrete composites at various hydration period. After 28 days curing, the mix with 5% NGPs shows the maximum compressive strength with 13.56% enhancement compared to E-waste concrete without NGPs. The mix with 1% NGPs was examined to have lowest increase in strength of 1.95%. Hence, it was concluded that incorporating NGPs in E-waste concrete significantly enhanced its compressive strength. Thus, a substitution proportion up to 25% can be utilized with manufactured E-waste coarse aggregate as the compressive strength achieved is more than the minimum compression capacity required for usually implemented concrete which is assessed to be 17.24 MPa [19].

Figure 3: Compression test Assembly a. Cylinder before test and b. Cylinder After test

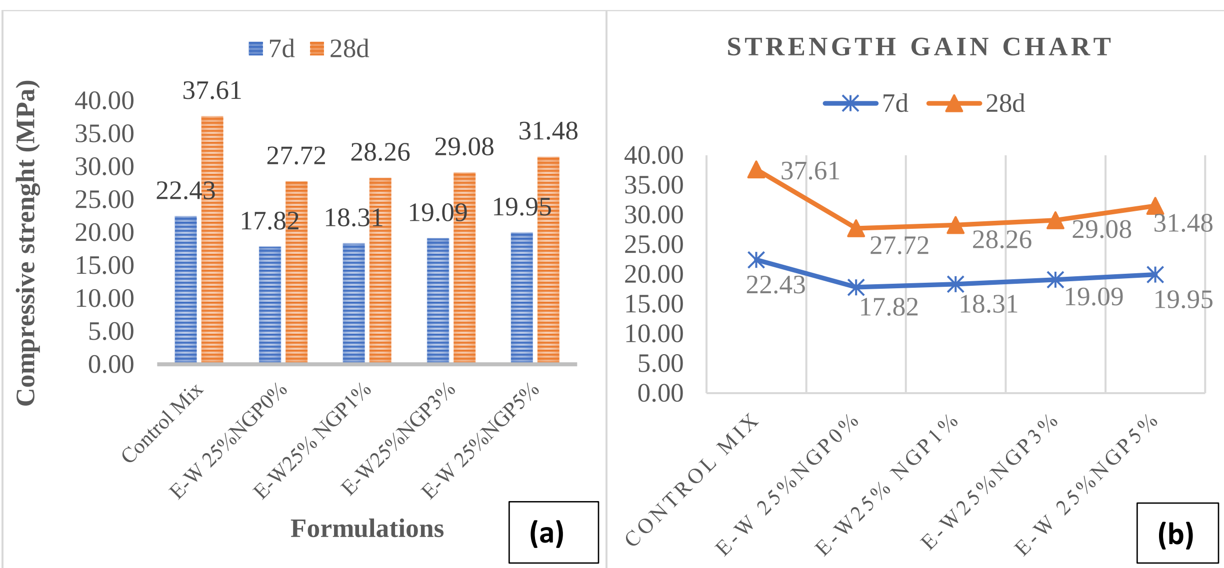

Figure 4: (a) Compressive Strength of NGPs composites incorporated with 25% E-waste and (b) Strength gain chart

4 Conclusions

From the research study, the following results regarding the NGPs reinforced composites containing the 25% E-waste aggregates has been drawn.

1. Dispersion of nano graphite platelets (NGPs) in water along with surfactant (AG) yield maximum dispersion at ratio of 0.6:1 (surfactant/NGPs ratio).

2. The compressive strength of E-waste incorporated concrete without NGPs was decreased by 26.3% after 28 days curing as compared to control samples. This is because of the weak bond formation between E-waste aggregate and cement paste. Also, it can be examined that the gradual increase in compressive strength was observed with increase in concentration of NGPs in the E-waste concrete mixes. The mix with 5% NGPs exhibits 13.56% higher compressive strength after 28 days curing as compared to E-waste concrete without NGPs. This increase in strength is due to the inclusion of NGPs which significantly improved density, hardness and reduced porosity thereby resulting an enhancement in the strength property.

3. A substitution of E-waste up to 25% can be utilized with manufactured E-waste coarse aggregate with reasonable compressive strength.

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