PHYSICAL, MECHANICAL, AND NON-DESTRUCTIVE EVALUATION OF GRIT IRON SCALE HEAVY-DENSITY CONCRETE

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Abstract- - In this study, heavy density grit iron scale aggregate is composed of concrete to assess its physical and mechanical properties. Grit iron scale aggregate was utilized in 25%, 50%, 75%, and 100% as coarse aggregate by replacing normal weight aggregate. Moreover, a control mix for comparison purposes was also developed. It was found that increasing the content of the grit scale tends to increase density and slump. The Compressive strength in rebound hammer was found maximum for concrete mix having a 50% grit scale. At the same time, ultra-sonic pulse velocity (UPV) tends to decrease by increasing the content of the grit scale. This study will help assess heavy-density concrete as a biological shield.

Keywords- Heavy density, grit scale, density, compressive strength.

1 Introduction

Concrete is primarily used as structural and protective material against harmful and ionizing radiation [1]. Concrete as a biological shield has been used from the very beginning due to its low cost, versatile nature, and ease of molding techniques [2]. Gamma rays, on the other hand, are used for food preservations, archeological sites, cancer therapy hospitals, and Nuclear Power Plants (NPP). These rays harm living cells due to their high penetration power and shorter wavelength. Therefore, the shielding of these harmful rays is evitable. For the same purpose, heavy-density concrete made from heavy-weight aggregates is primarily used as a biological shield against harmful gamma rays in NPP and related constructs such as nuclear waste storage compounds [3]. However, the radiation shield mainly and strongly depends upon materials' composition and density, especially aggregates. Therefore, heavy-density aggregates play a vital role as a biological shield in heavy-density concrete [4], [5].

Heavy Weight concrete is defined as a density greater than 2600 kg/m³ [6]. To achieve this density, need's special aggregate called heavyweight aggregate. For instance, magnetite, barite, limonite, steel slag, steel punching, and steel shots were used to achieve high-density concrete. Using magnetite aggregate, a concrete density of more than 3500 kg/m³ could be achieved [7]. In the contemporary study, barite, steel slag, and steel shots could yield concrete with densities of 3400 kg/m³, 5500 kg/m³, and 6500 kg/m³, respectively [8], [9]. ACI 304-3R91 (2004) and ASTM C637- 14(2019) describe the density and composition of aggregate for radiation shielding [10], [11]. A study recommends using magnetite aggregate to attenuate gamma rays more efficiently compared to normal weight aggregates [12]. Whereas Non-destructive testing (NTD) are widely used techniques to assess the quality of concrete, especially for post-construction. For example, the compressive strength and porosity of concrete have been assessed with a rebound hammer and ultrasonic pulse velocity (UPV) [13], [14].

In this experimental study, heavy density grit Iron scale aggregates are utilized in concrete to assess its physical and mechanical properties. This study will help study nuclear shields against gamma rays.

2 Research Methodology

ASTM Type-1 Ordinary Portland Cement (OPC) has been utilized in this study. Fine aggregate collected from a local vendor (Lawrancepur origin) with Fineness modules 2.6 was used. Normal weight Coarse Aggregate (NCA) from Margalla has been collected and utilized. The Heavyweight Grit iron Scale (HWGS) density of 3912.26 kg/m3 was collected from the foundry section of Heavy Mechanical Complex (HMC), Taxila, Pakistan. The physical and chemical properties of NCA and HWGS are given in table 1. The HWGS aggregate was a mix of both smooth and rough texture aggregates.

Table 1 Physical and chemical properties of HWGS and NCA

	Physical properties		**Chemical properties (%)**		
Aggregate Type	**NCA**	**HWGS**		**NCA**	**HWGS**
Density (kg/m3)	1550	3912.26	Fe	0.43	96
Hardness	7	9	Si	44.27	1.02
Color	Off white (limestone)	dark grey	Mn	0.03	1.2
Shape	angular	angular	C	-	1.2
Water absorption (%)	1.30	1.2	Cu	0.03	0.2
	-	-	Ni	0.06	0.15

For the compressive strength test, cubical molds of the control mix (having no Heavy Weight Grit iron Scale (HWGS) aggregates) and Heavy density Concrete were cast under controlled laboratory conditions. The Normal weight Coarse Aggregate (NCA) was replaced with 25%, 50%, 75%, and 100% HWGS designated as HDC1, HDC2, HDC3, and HDC4, respectively. After demolding, the concrete cubes were cured for 28 days in water under controlled laboratory conditions. After curing, the cubes were tested for compression in Compression Testing Machine (CTM) as per specifications laid by ASTM C 39/C 39M – 03. The workability of fresh concrete was also assessed in terms of Slump values ASTM as per the specification mentioned in C 143/C 143M – 03. The experimental program is shown in figure 1.

Grit scale aggregate Slump Casting

Compression Rebound hammer Ultrasonic pulse velocity

Figure 1: Experimental program

Chemrite SP3O3 superplasticizers were used to control the workability. For the HDC mixes, NCA was replaced with HWGS by volume method with constant water to cement ratio of 0.4. Moreover, for non-destructive evaluation, a rebound

Hammer and ultrasonic plus velocity tests were also carried out on concrete cubes. For each mix, the density at the 28 days of curing was also noted. The results of the density of concrete are shown in figure 2.

3 Results and discussion

3.1 Slump

The variations of slump value concerning grit scale content are shown in figure 3. The slump value for the control mix was 50 mm, whereas HDCI, HDC2, HDC3, and HDC4 showed Slump of 53 mm, 62.5 mm, 70 mm, and 87.5 mm, respectively. The slump is decreasing by increasing the content of HWGS. The slump variations may be explained due to the irregular and angular structure of grit scale aggregates which offers more interlocking effect and intra-particle friction and results in a harsh mix. Irregular aggregates find it difficult to move smoothly in a mix.

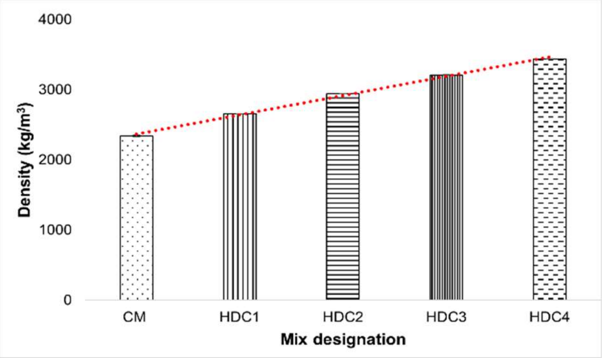

Figure 2: Density of concrete

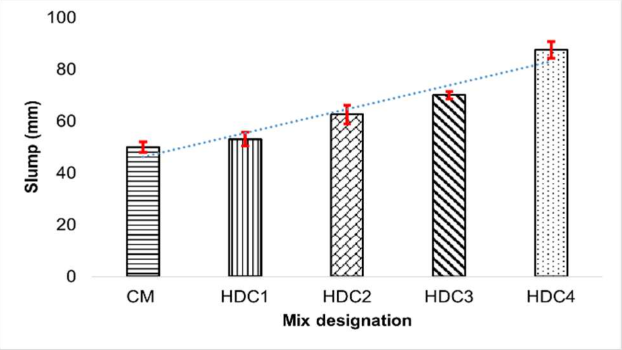

Figure 3: slump variations

3.2 Compressive Strength

Figure 4 shows the variations of the compressive strength concerning the content of HWGS. The compressive strength observed for CM was found to be 20.5 MPa. Whereas HDC1, HDC2, HDC3, and HDC4, showed a maximum compressive strength of 20.8, 25.6, 22.5, and 19.7 MPa, respectively. The results show that up to 50% replacement of NCA with HWGS tends to increase the strength, whereas it decreases by increasing the HWGS content beyond this replacement. This is because the grit scale aggregate tends to make stronger bonds due to its irregular and angular texture. However, increasing the content of HWGS lacks an interlocking effect due to the abundance of aggregates, resulting in low strength.

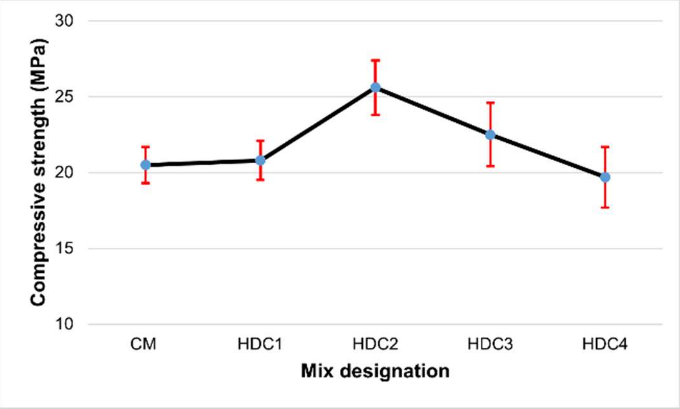

Figure 4: Compressive strength of concrete

3.3 Rebound hammer

The rebound hammer results indicate that the maximum value was obtained for HDC2 having 50%. HWGS was found to be 33 and lies in the "Good Layer" of the concrete quality. The lowest was noted for HDC4, which was found to be 22 and lies in the “poor Concrete” category. The rebound hammer result is shown in figure 5. As mentioned in section 3.2, compressive strength was found maximum for HDC2 mix due to good interlocking effect and irregular aggregates shape. The same criteria and engineering knowledge could be applied to the rebound hammer. Due to its compact and dense structure, the mix showed good rebound values due to the hardness of the mix.

3.4 Ultra-sonic plus velocity (UPV)

The UPV test shows opposite results compare to the compressive strength and rebound hammer. The lowest UPV value was found for CM, and the largest was for HDC4. This is because grit scale aggregates are composed of heavy and dense structures with high atomic weight. The pulses of UPV are easily attenuated by the dense atomic structure of the concrete due to the inclusion of grit scale aggregate, resulting in more value. The grit scale has a density of more than 3.9 g/cm3, meaning the aggregates are densely packed with atoms. Therefore, UPV rays find it difficult to pass through such densely packed structures. Therefore, a linear trend in UPV increment could be observed for concrete by increasing the content of HWGS as shown in figure 6.

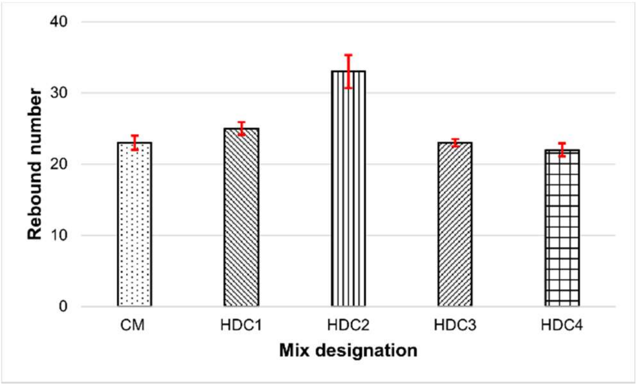

Figure 5: Rebound hammer results

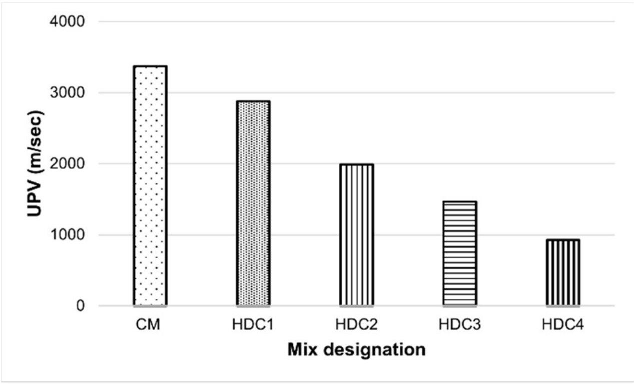

Figure 6: Ultrasonic Pulse Velocity test variations

4 Practical implementation

This study deals with developing heavy-density concrete by incorporating heavy-density grit iron scale aggregates. This study could be efficiently implemented in gamma irradiation facilities. The gamma irradiation facilities include nuclear power plants, cancer therapy rooms, nuclear waste storage facilities and research laboratories. Heavy-density concrete is made from aggregates that possess more atoms per unit area. Thus, such concrete can efficiently attenuate gamma rays compared to normal weight concrete. Moreover, heavy-weight concrete could also be utilized in underwater structures where more weight is required to sink the concrete at the bottom of a water body. Also, heavy-density concrete could also be used for counterweights such as overhead cranes working on site.

5 Conclusion

In this study, heavyweight grit iron scale aggregates were incorporated into the concrete to study its physical and mechanical properties. The following conclusion could be made:

- HDCI, HDC2, HDC3, and HDC4 showed slumps of 53 mm, 62.5 mm, 70 mm, and 87.5 mm, respectively. The slump decreased by increasing grit scale aggregates due to irregular and dense structure.

- HDC2 mix showed 25.6 MPa compressive strength as maximum among mixes. This is because an excellent interlocking effect was observed in grit scale, and compacted concrete structure was formed.

- Rebound hammer for HDC2 mix was found more due to the dense and compact structure of the mix.

- Ultrasonic pulse velocity was found to be minimum for the control mix (3400 m/sec) while the maximum for the HDC4 mix (980 m/sec). The UPV rays travel difficult in dense atomic structures; hence increasing the grit iron scale tends to show a good result for UPV.

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