Southern Journal of Engineering & Technology – Special Issue, Vol. 01, Issue 01, 2024

Investigation of Mechanical Properties and Drying Shrinkage of Normal and Heavy Weight Concrete

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Abstract: Concrete is the most commonly used construction material. Application of both Normal Weight concrete (NWC) and Heavy Weight Concrete (HWC) is prevalent in the construction industry, NWC usage is more extensive in comparison to HWC, however, concrete has many complexities including drying shrinkage. After hardening of concrete, water evaporates from the concrete and leaves pores in concrete. Concrete tends to change volume and tries to shrink and fill that pores but restraints in concrete causes it to crack. Drying shrinkage is an everlasting process because once the cracks appear, water particles enter into these cracks in the form of humidity or moisture and evaporate again. There are many factors which affect the drying shrinkage like fineness of cement, admixture used, type of coarse aggregate, w/c ratio, type of concrete etc. The mechanical and time dependent properties (drying shrinkage) are investigated in normal and Heavyweight concrete in a manner to perform the comparative analysis. It was concluded that the HWC can be used for structural works due to its better performance. The strength of concrete containing heavy aggregates increased significantly over time; by day 14, it had reached 85% of its total strength. By day 28, it had improved even further, reaching a compressive strength of 38.2 MPa. Further, the use of heavy aggregates decreases the shrinkage of concrete because their rough surfaces let cement paste and aggregates adhere better, increasing strength and reducing shrinkage.

Keywords: Heavy Weight Concrete, Drying Shrinkage, Normal Weight Concrete, Mechanical Properties.

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1. Introduction

The concrete demand is growing day by day with the population increase and infrastructure development. Many types of aggregates are being used to enhance the characteristics of concrete for the improvement in quality of concrete. In all types of construction, it is essential to produce a product that is durable. The materials used must perform the required function under all conditions to which they are exposed. The acceptance of new materials then depends on their ability to perform as designed under the conditions they encounter. In the past two decades a large amount of research has been devoted to characterizing synthetic aggregates. Concrete has many problems considering its tensile strength, shear behavior and shrinkage of concrete that occurs due to the volume change in concrete with removal of moisture from the concrete. Volumetric change of concrete is divided in thermal change, creep and shrinkage. Shrinkage is basically the change in volume due to drying and chemical changes, depends on time. It is not affected by the stresses induced by external loading. This study is dealing with the shrinkage of heavyweight concrete.

The durability is affected by the entry of water through cracks, which corrodes reinforcing steel, leaches out soluble components, and accelerates deterioration due to freezing and thawing. Other shrinkage related problems are warping, prestress loss, reduced effective tensile strength, and excessive deflections in unsymmetrically reinforced members. The problem being considered in this report is the shrinkage behavior in Normal weight concrete and Heavyweight concrete. This study compares the mechanical and time dependent behavior of NWC and HWC.

2. Literature Review

Structural concrete is being used construction material in civil engineering structures (Topçu, 2003). It has good endurance to water and can be made in variety of shapes (Facure & Silva, 2007). Now a days, the concrete industry annually consumes 1.5 billion tons of cement, 10-12 billion tons of aggregates and 1 billion tons of water (Kazjonovs, Bajare, & Korjakins, 2010). A huge number of natural resources are being utilized for concrete production (Ouda, 2015). Because of this, even a small reduction in the environmental impact will result in major advantages to the environment (Silva, Brito, & Dhir, 2014).

It was investigated that the aggregates control the properties of concrete. The effect of aggregate is studied on drying shrinkage of concrete. According to results obtained, the shrinkage of aggregate is strongly related to the shrinkage of concrete. Lightweight aggregate offers less restraint on shrinkage of cement paste then the large shrinkage of concrete. However, the actual shrinkage of lightweight concrete is small. It was explained that because of the small shrinkage of LWA, shrinkage of lightweight concrete is small. The shrinkage of normal aggregate is high so focus should be on the usage of normal aggregate (Fujiwara, 2008).

It was studied about the effect on shrinkage within or without fly ash on heavyweight magnetite concrete. 0% to 100% for 25% and fly ash ranging 5% to 25%. For comparing with CEB-FIP equation, five different concrete mix can be prepared for finding shrinkage. Test shown that HWC is more affected. GL 2000 model are used for HWC shrinkage. This type of method is useful to increase the prosperities of aggregate (Li & Yao, 2001), Heavyweight concrete was investigated, and this type of concrete is used in bridge construction or nuclear power plant for reducing the effect of dangerous radiations that can affect domestic lives and causes various diseases (Demir et al., 2011). A comparison was made between the test results performed on drying shrinkage and analytical models at early ages. For New Jersey Department of Transportation (NJDOT), HPC mix were developed and implement that was used. For early age perform of HPC, three curing methods were evaluated. The conditions for curing are Burlap, air drying and curing compound. The results revealed that to improve early age performance burlap should applied within one hour. For improved shrinkage performance very low water cement ratio was used (Mahdy, Speare, & Abdel-Reheem, 2002).

It was studied that high strength concrete contains heavyweight aggregates. The aggregates have their influence on the shrinkage of concrete. The more the shrinkage in the aggregate, more the shrinkage will be in concrete. It has been investigated that the coarse aggregate characteristics influence the shrinkage of concrete (Chan, Peng, & Chan, 1996). The Shrinkage is also affected by the temperature, humidity and wind speed at the time of concrete casting and it can be controlled by proper curing of concrete.

3. Methodology

In this study, the heavyweight concrete was made using steel waste pieces as coarse aggregates in the concrete. The main objective of this study is to check mechanical properties and drying shrinkage in Normal and Heavyweight concrete by using steel pieces as a coarse aggregate in HWC. All the procedures used were according to the ASTM standards to assure the quality of concrete so that it can help to achieve research objectives.

3.1 Collection of Material

The steel was originally bought from Lahore. Twelve kg of steel is procured and processed by cutting the steel into irregular pieces of 10 to 20 mm in size by using gas cut. This technique was selected to preserve an uneven and rough surface, which is essential for a good bond with the cement paste in concrete. Figure-1 shows the steel aggregates before and after cutting, are also mentioned in the paragraph.

3.2 Mix Design

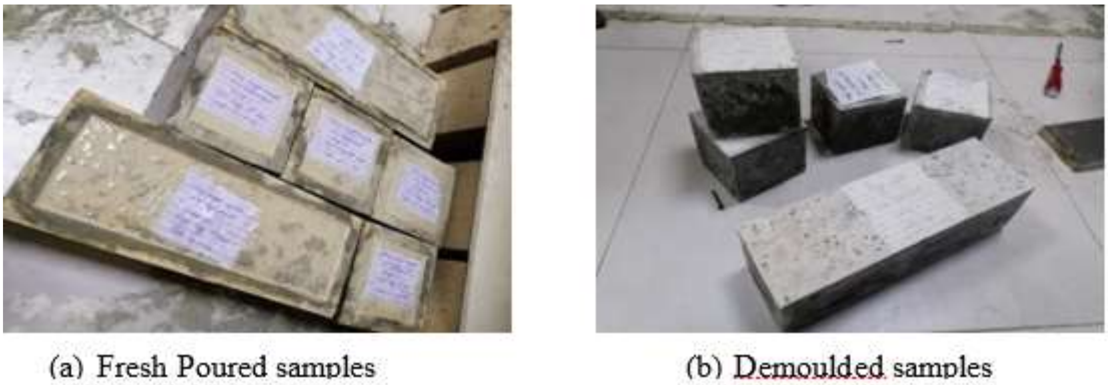
After Collection of material, various tests were performed on cement, sand and aggregate to conduct mix design for concrete mix. The mix design used for this study is 1:1.75:2.1. The heavyweight concrete was developed using 10%, 20% and 30% steel aggregates. The Mix NWC stands for control concrete and the other mixes contains steel aggregates. The detailed aggregates can be seen in Fig. 1. The water to cement ratio for the mixes was 0.36 and 1% super plasticizer was used for proper handling of concrete. The aggregate to binder ratio was 3.85.

Concrete cubes and prism of dimensions 100mm*100mm*100mm, 100mm*100mm*500mm and 100mm*100mm*300mm were casted as shown in Figure 2 for the experimental evaluation of compressive strength, flexural strength and drying shrinkage respectively.

Figure 1 Steel Aggregates

Table 1 Mix Design

Concrete Type	Content [kg/m^3]					SP (% cement)
	Cement	Sand	Coarse Aggregate	Steel	Water	
NWC	450	790	945	-	162	1
HWC-10	450	790	850.5	33.4	162	1
HWC-20	450	790	756	66.8	162	1
HWC-30	450	790	661.5	100.2	162	1



(a) Fresh Poured samples (b) Demoulded samples

Figure 2 Demolded Specimen

4. Results and Discussion

4.1 Densities of Prepared Concretes

After demolding of specimen, the unit weights of the concrete mixes were measured, which is known as the demolded density. Figure-3 shows the demolded densities of the mixes. It can be seen from the table that density is increasing by increasing the percentage of heavy aggregate mix. Heavier aggregates have more density as a result they increase the overall density of the concrete making it heavier. HWC-30 is almost 15% heavier than NWC.

4.2 Compressive Strength

Compressive strength is the capacity of a material or structure to bear the axial loads tending to reduce the size. It is measured using the Universal Testing Machine. In this study the compressive strength of concrete specimens was found using compression testing machine. Four mixes and three prisms of each kind were casted for normal weight concrete and heavyweight concrete. The results for compressive strength are shown in Figure 4. Because heavyweight aggregates are stiffer and have a larger density than conventional aggregate, HWC results in a higher compressive strength. In concrete constructions, these aggregates support most of the weight. Previous studies reveals that the denser particles used in heavyweight concrete contribute to its greater strength. The steel utilization as coarse aggregate results in uneven, rough surfaces that improve bonding with the cement paste, which adds to its strength. The strength of concrete containing heavy aggregates increased significantly over time; by day 14, it had reached 85% of its total strength. By day 28, it had improved even further, reaching a compressive strength of 38.2 MPa.

The compressive strength of many concrete mixtures with various percentages of heavyweight aggregate replacements was tested. Compared to NWC, HWC-10 demonstrated greater strength with replacement levels of 10%: 29.78 MPa on day 7, 37 MPa on day 14, and 43.17 MPa on day 28. Even greater strengths were shown by HWC-20 and HWC-30, with HWC-30 reaching 55.48 MPa on day 28. Since heavier particles produce concrete that is stronger and more load bearing, the heavy aggregates in these mixes greatly increased the strength of the mixtures. Strength was further increased by the heavy aggregate's rough surfaces, which improved the binding with cement paste. Heavyweight concrete performs better in compression tests than regular concrete because of its stronger, tougher, and denser characteristics.

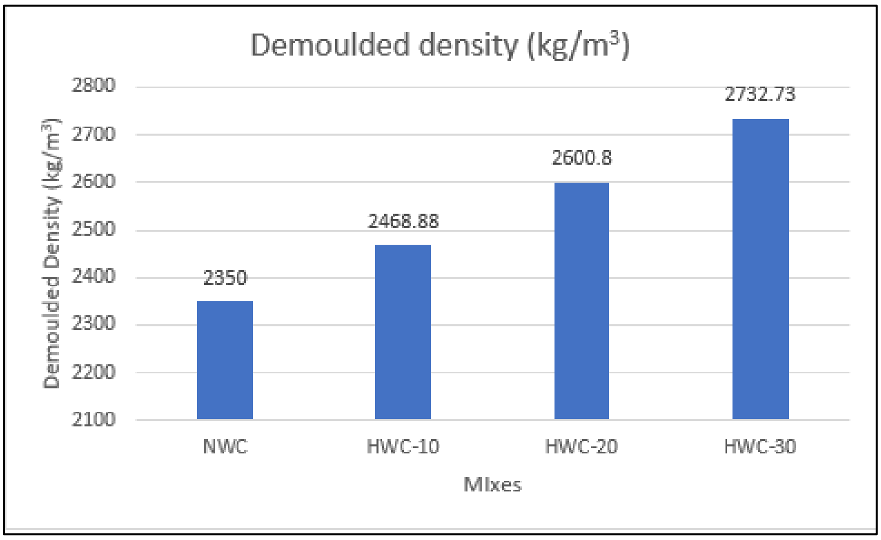


Figure 3 Demolded Density

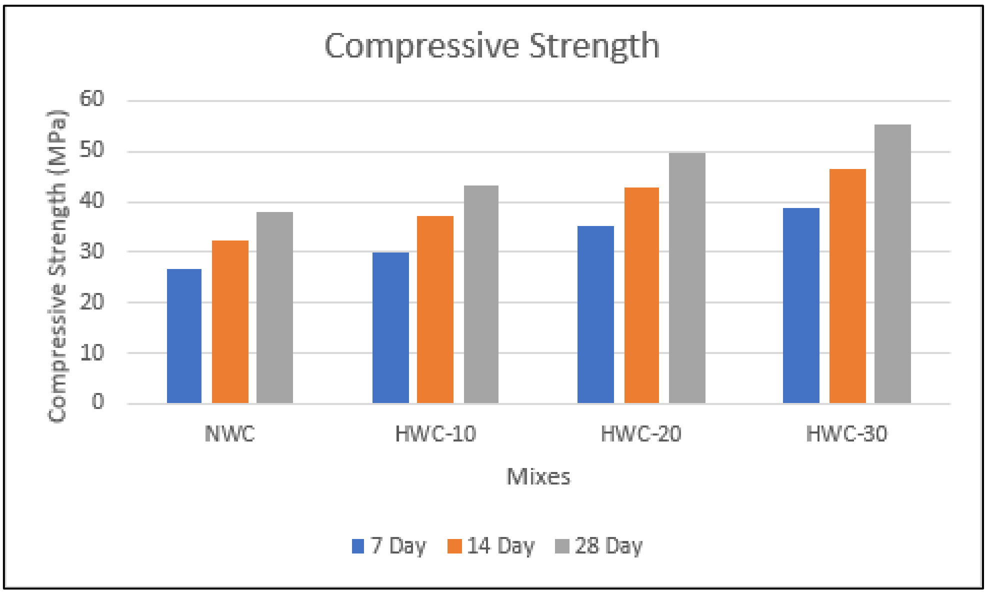


Figure 4 Compressive strength of Concrete

4.3 Flexural Strength Test

Flexural strength of concrete is determined as an index of tensile strength of concrete. Tensile stresses are most likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and other different reasons. Prisms tests were conducted to determine flexural strength of concrete. Flexural strength tests were conducted on prisms of dimension 100mm x 100mm x 500mm. Three specimens each for normal weight concrete and heavyweight concrete were casted at varying percentages of steel as coarse aggregate. In each case the 28-day strength values were obtained by loading under an apparatus for flexural strength. Flexure strengths of different specimens is shown below in Figure 5. The graphical representation clearly shows that flexural strength also increased with the increment of the heavy aggregates. It also showed a similar behavior like compressive strength. The possible reasons can be same those as explained earlier.

Compared to regular weight concrete, the heavyweight concrete has a higher flexural strength, which allows it to withstand larger loads. The utilization of heavier aggregates with higher density, hardness, and abrasion resistance is what gives the material its strength advantage. These aggregates are stronger due to their higher specific gravity and unit weight as well as their rough surfaces, which improve bonding with cement paste. For example, at day 28, HWC-30 could support nine times the load of NWC. Because of its intrinsic strength capabilities and strong bond with cement paste, heavy concrete beats standard concrete significantly, even if the improvement in flexural strength may be slightly smaller than in compressive strength.

4.4 Drying Shrinkage

Even in the absence of external force or temperature fluctuations, concrete can experience strain from shrinkage as a result of water loss and cement hydration. A little amount of this shrinkage can be reduced by carbonation through wetness. Shrinkage is influenced by a number of variables, including air humidity, surface area for moisture loss, mix proportions, carbonation, self-desiccation, and curing time. Prism specimens of 100 mm by 100 mm by 300 mm were used for the tests on both heavyweight concrete (HWC) and normal weight concrete (NWC), which were kept indoors to reduce humidity variations. Demountable Mechanical Gauge (DEMEC) points were used to monitor shrinkage strains by fixing stainless steel DEMEC points 200 mm apart along the center axis. The readings were taken using DEMEC Mechanical Strain gauges, with measurements averaged to determine the shrinkage strain. Figure 6likely shows the process of taking readings from the specimens using the gauge mechanism.

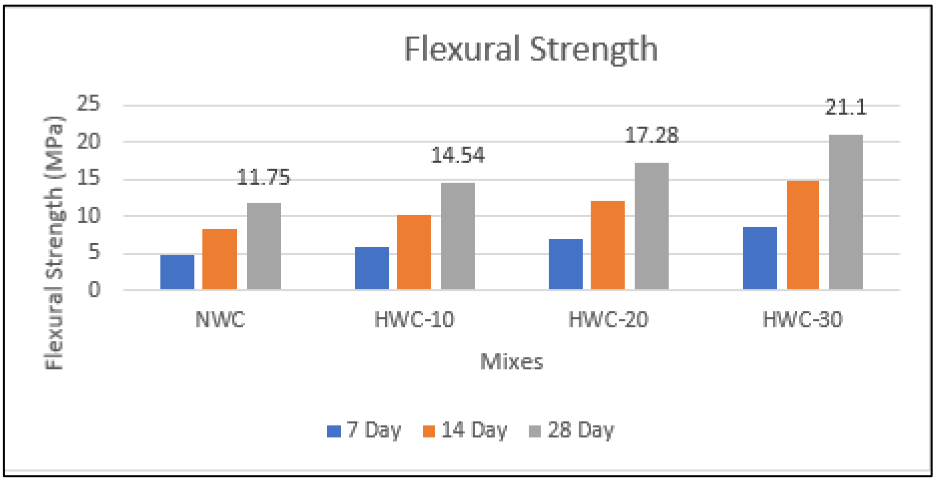


Figure 5 Flexural Strength of Concrete

Figure 6 Drying Shrinkage of Concrete

Table 1 Drying Shrinkage of Concrete

Age (days)	Drying Shrinkage (micro strains)			
	NWC	**HWC-10**	**HWC-20**	**HWC-30**
1	0	0	0	0
2	21	23	20	19
3	43	46	44	40
6	89	82	83	76
8	109	104	98	88
10	139	130	119	99
14	163	158	149	126
17	187	179	161	139
23	219	214	183	164
25	234	226	192	173
28	241	237	210	184

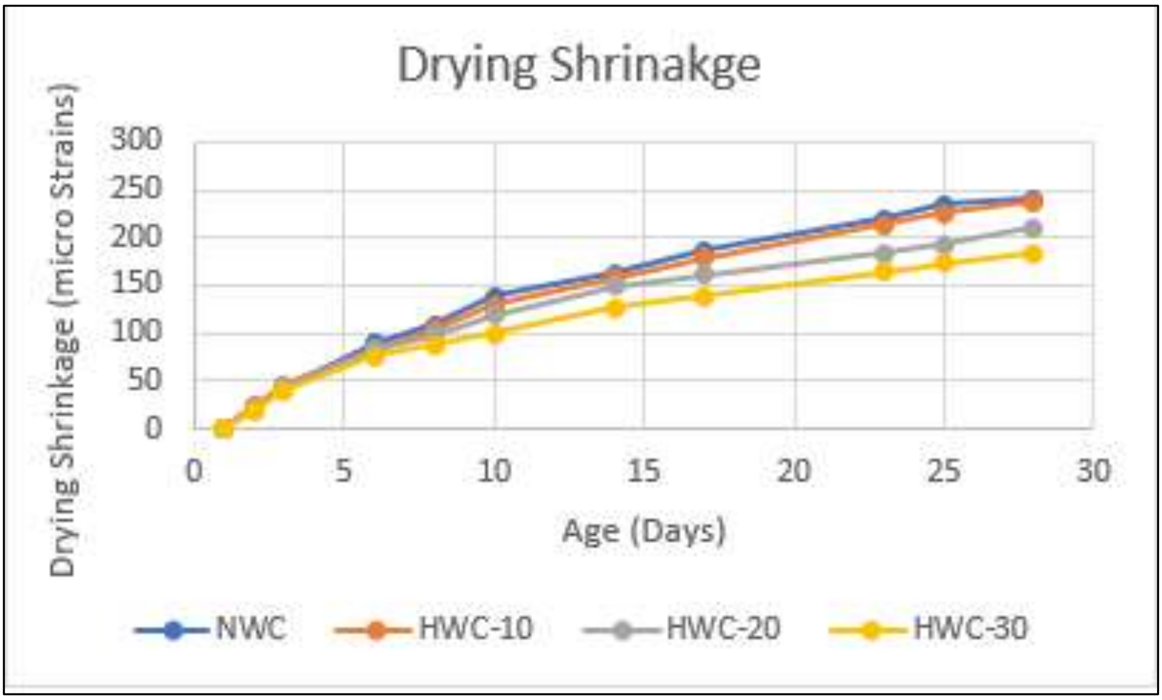


Figure 7 Drying Shrinkage of Concrete

4.5 Drying Shrinkage Development

When steel is used as coarse aggregate in concrete, drying shrinkage decreases with the increase in the substitution ratio of steel, since it is affected more by the higher density than the higher water absorption of steel. Thus, steel can be used to reduce drying shrinkage in concrete (So Yeong Choi, Sun Kim, 2020). Drying Shrinkage values of the specimens are shown below in Table 2. The graphical representation Figure 7 shows that in the first few days the drying shrinkage is the same as normal weight concrete, but as the days passes the change can be seen in the concrete that normal weight concrete has much more drying shrinkage than the heavyweight concrete. Over the course of four weeks, the drying shrinkage behavior of heavyweight concrete (HWC) and normal weight concrete (NWC) was investigated. Due to the high initial water content from curing, both types of concrete showed rapid drying shrinkage in the first week, as study has shown. Similar trends remained in the second week, indicating ongoing volumetric changes and evaporation. However, as the water content decreased over time, resulting in less evaporation, and shrinking, drying shrinkage values started to decline by the third week. Because normal aggregate made up most of the mix, drying shrinkage patterns were initially similar when comparing NWC with HWC-10 (10% aggregate replacement). In comparison to NWC, HWC-20 and HWC-30 both showed reduced drying shrinkage; however, HWC-30 showed the largest reduction, highlighting the impact of heavy aggregates on reducing drying shrinkage in concrete mixes.

5. Conclusion

The HWC can be used for structural works due to its better performance. The steel utilization as coarse aggregate results in uneven, rough surfaces that improve bonding with the cement paste, which adds to its strength. The strength of concrete containing heavy aggregates increased significantly over time; by day 14, it had reached 85% of its total strength. By day 28, it had improved even further, reaching a compressive strength of 38.2 MPa. In comparison of HWC to NWC, drying shrinkage is less in HWC, with HWC-30 exhibiting the most reduction.

The use of heavy aggregates is responsible for this decrease in shrinkage because their rough surfaces let cement paste and aggregates adhere better, increasing strength and reducing shrinkage. HWC-30 is a good choice for applications needing greater strength and less drying shrinkage since it also shows better compressive and flexural strengths than NWC. The qualities of HWC are further improved by the addition of fibers, admixtures, and the right amount of cement, which makes it a viable option for reducing drying shrinkage and enhancing the overall performance of concrete.

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