American Journal of Technology Advancement 2997-9382, Vol 03, No. 02, 2026

Article

Utilisation of Crushed Interlock as Coarse Aggregate in Concrete

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Abstract: The aim of this research was to create eco-friendly forms of concrete by using recycled aggregates (RA) from construction sites to replace natural aggregates (NA). The study involved multiple levels of using coarse crushed materials as a substitute for gravel. This study focused on determine how the use of interlock waste crushed into RA would affect the physical/mechanical properties of Concrete when replacing coarse NA. Four different levels of weight were tested at a 25%/50%/75% and 100%, respectively. The physical properties were evaluated using slump testing, water absorption testing and dry density measurements while the mechanical properties were evaluated using flexural strength testing, compressive strength testing, and splitting tensile strength testing. For all specimens, all three types of the specimens were monitored for 28 days. Results indicated the influence of RA on the physical/mechanical performance of all tested specimens.

Keywords: Recycled Aggregates (RA), Eco-Friendly Concrete, Mechanical Properties, Physical Properties, Natural Aggregate Replacement.

1. Introduction

The increased population means there are more people generating more types and amounts of waste. Many of the materials that cannot break down in nature stay in our environment for hundreds of years, causing many of the problems associated with the growing crisis in managing our waste and causing problems to our environment. The total number of individuals on the planet at the start of the twentieth century was around 1.5 billion. By the end of that same century, it would have grown to 6 billion people globally; thus, representing an increase of approximately 4 times from that original count over a single century demonstrates how quickly populations can grow. According to experts, the world's population will reach roughly 10 billion people by the year 2050 [1]. With higher planned need for concrete manufacturing, the projected population growth has put immense pressure on the countries' infrastructure and development needs. More than 11.6 billion tons of concrete are produced worldwide each year, of which 9 billion tons are made up of aggregates, both coarse and fine. According to projections, the output of concrete would expand to 18 billion tons yearly by 2050 as a result of the rapid population expansion [2]. On the other hand, increased population development resulted in a rise in the volume of solid waste being disposed of, including recycled aggregates. Because crushed interlock is durable, non-biodegradable, and has a long lifespan, it is one of the most environmentally damaging forms of solid waste. Many large urban centres experience significant amounts of crushing and rehabilitation work before any major new construction takes place as part of their overall construction industries. However, this activity produces a significant amount of garbage from construction and deconstruction. The EU Building and Demolition Waste Management Protocol (2016) reported that in 2016 Europe produced 3.5×10^8 tonnes of construction and demolition (C&D) waste, which makes it the largest waste stream in Europe and also accounts for approximately one-third of the total amount of waste that was produced (Eurostat, 2021). C&D waste was also estimated by the Construction & Demolition Recycling Association to have been 5.8×10^8 tonnes in the USA in 2015 (Martín-Morales et al., 2011), and it is estimated to account for 20–30% of all municipal solid waste. Typical people and companies will generate many different materials as waste when they build or demolish something; some of those materials will be concrete, brick, ceramics, metal, rock, plaster, glass, soil, asphalt, and wood (Medina et al., 2015; Villoria et al., 2011).

Certain types of construction waste, such as those that contain asbestos, have paint coatings made of lead, and lighting waste, may pose special health, safety, and environmental risks. These resources are not a part of this investigation.

New approaches to re-purposing waste are being continuously researched to create a safer and more cost-effective option for disposal. The use of recycled aggregates helps conserve natural resources, reduces the need for landfill resources, and promotes sustainability of the environment. This research evaluates utilizing of construction waste as a sectional replacement for conventional aggregates used in standard Portland cement concrete mixtures.

The issues with natural aggregate quarrying and the disposal of old concrete can be resolved by recycling concrete as aggregate. Numerous research investigations were carried out since these alternatives necessitate comprehensive examinations to determine how they affect the properties of concrete. Wilson (1993) investigated how the qualities of concrete mixtures were impacted by the crushed concrete's irregular surface. Some researchers examined plastics and glass wastes as aggregates in concrete mixtures. The potential application of glass and plastics powder in different civil engineering and building uses has been explored by many researchers (Chanbane et al., 1999; Rindl, 1998; Shayan et al., 1999).

Crumb rubber was employed by Sukontasukkul and Chaikaew (2006) to alternate out the harsh and fine particles in concrete pedestrian blocks. This led to soft blocks, which gave the surface some softness. Additionally, crumb rubber blocks conducted very well in tests of abrasion and skid resistance.

The paremount goal of this study is to examine how the conventional Portland cement combination performs when recycled waste materials, namely crushed interlock, are utilized as a portion of the mix's aggregates. This will be shown by laboratory experiments employing crushed interlock instead of a specific percentage of coarse aggregates in conventional Portland cement (OPC) concrete, along with natural fine aggregates (sand), i.e., the concrete mixture physical and mechanical properties using partial natural coarse aggregate as replacement by crushed interlock waste.

2. Materials and Methods

The goal of the study was to test the effect on concrete properties of different ratios of crushed interlock waste (recycled aggregate, RA) and partially replacing natural coarse aggregates (NA) with them. The research determined the best replacement ratio by testing concrete samples containing only NA and those with various amounts of RA, allowing for comparisons between the two.

2.1 Materials

2.1.1 Cement

In this study, regular Type I (Portland cement) is employed. The Iraqi Specification No. (5/1984) [14] and ASTM C150-04[15] standards meet the chemical composition and physical specifics of cement.

2.1.2 Aggregates

The coarse aggregates are made of crushed the maximum size of the natural stones with of 20 mm, while the fine aggregates are made of with maximum size of natural sand of 4.75 mm from Basra city in southern Iraq. Table 1 and Fig. (1) show the grading and specifications for fine aggregates, which are in accordance with Iraqi Standard Specification No. 45/1984[16] and ASTM C33-03[17]. Table 2 shows the physical properties of natural graval according to Iraqi Standard Specification No. 45/1984.

2.1.3 Crushed interlock aggregates (RA)

The crushed interlock waste is used to obtain crushed interlock aggregate (RA). All aggregates are passed from sieve size 20 mm. According to Iraqi Specification No. 45/1984 for gravel, the sieve analysis of the crushed interlock particles met the requirements [16]. See Table 2. Fig. (2) shows the natural and crushed interlock aggregates.

2.2 Mix proportions

In order to achieve the closest approximation to reality, one of the most used weight ratios for mixing (1:1.5:3) is used, with intension strength of (35 MPa) at (28 days). The mixture contains 254.54 kg of cement, 436.36 kg of sand, and 981.82 kg of gravel per cubic meter. The ratio of water to cement is 0.48. Crushed interlock wastes are added to the baseline mix in four different percentages 25%, 50%, 75%, and 100% as a sectional replacement for natural coarse aggregate, per pre-experiments study. The proportions of the concrete mix are listed in Table 3.

2.3 Preparation of the specimens

Before being used in the mixes, all aggregates are cleaned and washed. Prior to casting, all molds (cylinders, prism, and cubes) are ready, cleaned, and lubricated (Fig. [3]). The aggregates, which also include crushed interlock waste replacements, are mixed using an electric mixer. The concrete mixture was then supplemented with cement. Finally, the mixture was gradually added to the water while being continuously mixed. At least two minutes were spent mixing.

2.4 Laboratory tests

This research evaluated fresh concrete and hardened concrete samples that consisted of cubes, cylinders, and prisms regarding their physical and mechanical properties. Properties evaluated for each sample were slump, water absorption, dry density, flexural strength testing, compressive strength testing. Each percentage of replacement specified in the project was compared with a reference mix. For each test performed, 9 Concrete Cubes (150x150x150mm) were produced; 3 of these were tested for compressive strength after 28 days in the laboratory. The cylinders were tested for splitting tensile strength while using a 100x200mm cylindrical specimen, and the Flexural Strength was assessed with a 100x100x500mm prism specimen at 28days per ASTM C293 Method A (Single Point Method) [18].

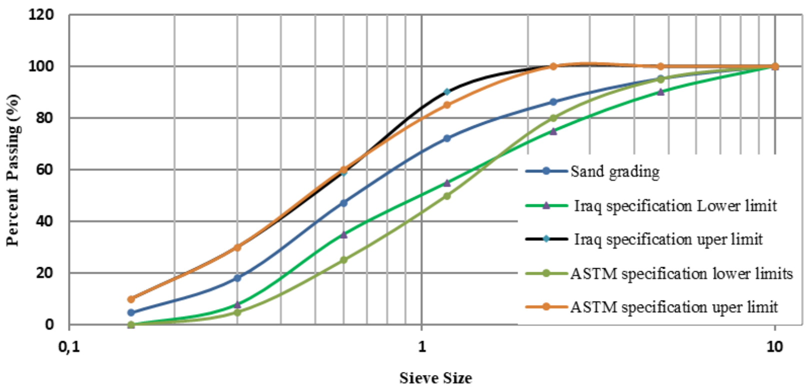

Figure 1. Grading Curve for Original Fine Aggregate.

a) Natural Aggregate **b) Crushed Interlock Aggregate**

Figure 2. Type of coarse aggregate.

Figure 3. The specimens test casting for one replacement percentage.

Table 1. The Fine Aggregate Physical Properties.

Physical properties	*Sand test results*	*Limits of Iraqi specification No.45/1984 for sand*
Specific gravity (s.g)	2.56	-
Sulphate content (%)	0.13	≤0.5%
Absorption (%)	0.75	-

Table 2. The natural coarse aggregate (NA)and crushed interlock aggregate (RA) Physical Properties.

Physical properties	*NA results*	*RA result*	*Limits of Iraqi specification No.45/1984 for sand*
Specific gravity (s.g)	2.64	2.33	-
Sulphate content (%)	0.07	-	0.1% (max)
Absorption (%)	0.96	4.76	-

Table 3. Concrete mixture proportion for all replacement ratio (w\c= 0.48).

Material(kg/m^3) **RA/NA**	Cement	Sand	**NA**	Water	**RA**
0%	254.54	436.36	**981.82**	191.25	**0**

25%	254.54	436.36	**736.37**	191.25	**245.46**
50%	254.54	436.36	**490.91**	191.25	**490.91**
75%	254.54	436.36	**245.46**	191.25	**736.37**
100%	254.54	436.36	**0**	191.25	**981.82**

3. Results and Discussion

3.1 Slump test

ASTM C143 [19] is followed when conducting the slump test. The findings indicate that as the amount of crushed interlock debris in the concrete mixture grows, the workability of the concrete diminishes. In comparison to the reference mix, the 100% replacement rate results in a greater drop in concrete workability (12%) (Fig. (4)). Because crushed interlock particles have a higher surface area than natural coarse particles, they allow for more water to be absorbed into their surface, which lowers the workability of concrete. Additionally, the crushed interlock particles' considerable porosity.

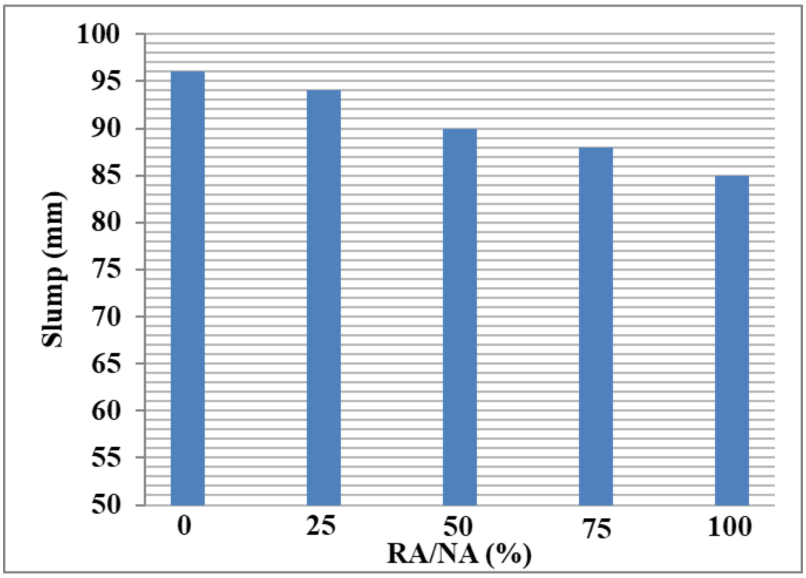

Figure 4. Slump to (RA/NA) relationship.

3.2 Absorption test

A test was conducted in accordance with ASTM C642 [20].In this test, cube-shaped specimens with dimensions of (150 x 150 x 150) mm are employed. Samples were examined when they were 28 days old. The findings demonstrated that when the percentage of crushed interlock increases, the absorption rate rises. Previous research has supported this result [21, 22]. The absorption rate of the reference mixture is 2.833%, and the absorption rate of the specimens with 100% crushed interlock replacement is 4.348%, which is 54% greater than the absorption rate of the former (Fig. (5)). This phenomena may be caused by the crushed interlock particles' asymmetrical shape and jagged edges, which increased the amount of gaps and pores in the concrete structure and enhanced the absorption rate.

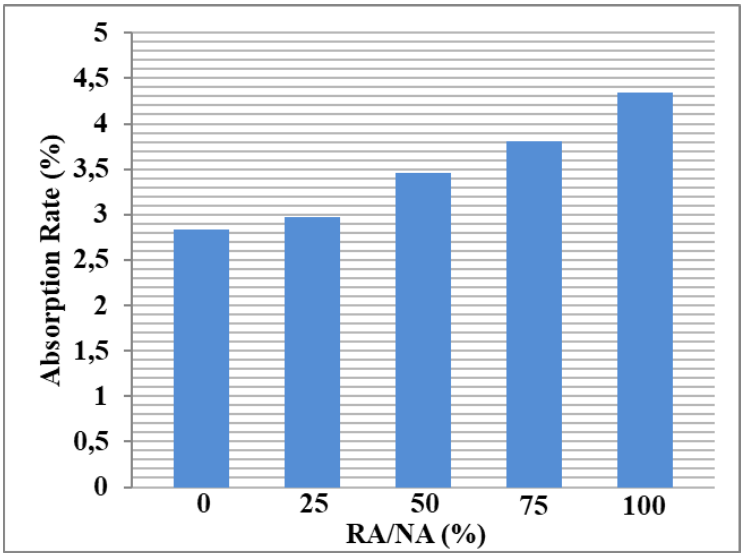

Figure 5. Absorption to (RA/NA) relationship.

3.3 Dry density

According to the findings of the dry density measurements, adding crushed interlock waste particles to the concrete mixture decreased the dry densities of the concrete (Fig. 5). These findings are consistent with and supported by other research [23]. Due to the low density of the crushed interlock particles (2127.65 kg/m3), increasing the percentage of crushed interlock to 100% lowered the density of concrete in comparison to the reference mix. In some situations, such as with large concrete structures on unstable soils, this very slight drop may be helpful in lowering the static load of concrete. In Fig. (6), the test findings are summed and presented as percentages against the link among concrete density and crushed interlock waste replacement. When the amount of crushed interlock material in concrete increases, the density curve typically declines.

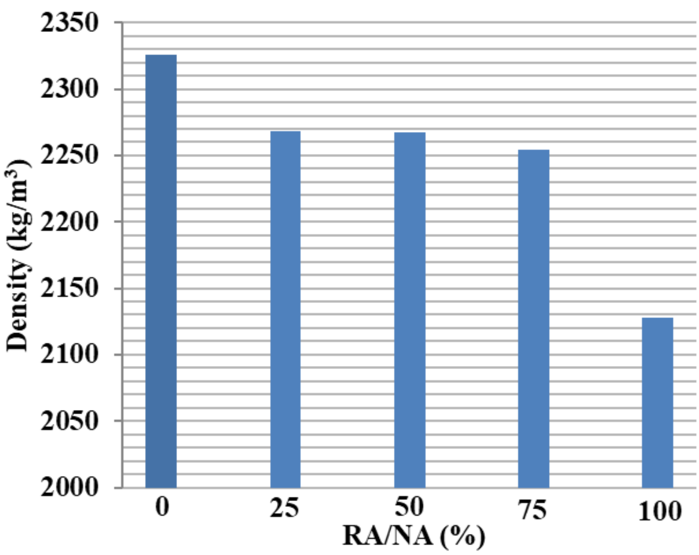

Figure 6. Dry density to (RA/NA) relationship.

3.4 Compressive strength

Using a compression machine with a 2000 kN capacity, this test was conducted in accordance with B.S.1881, Part 116[24]. When crushed interlock waste replacement percentages vary from 25%

to 75%, the compressive strength rises (Fig. (7)). The best proportion is 50% for an 18% improvement in compression strength after 28 days. Additionally, the compressive strength enhance by 13% and 11%, respectively, when the replacement ratio of crushed interlock waste was 25% and 75%. The compressive strength of the cubes with 100% crushed interlock waste replacement is reduced by 14%. When the replacement ratio for crushed interlock waste is low, the compressive strength increases. The specimens with crushed interlock waste percentages of 25%, 50%, and 75%, respectively, show increases of 13%, 18%, and 11%. When the applied load extended the ultimate load, the mode of failure (i.e., the internal stresses change from shear stresses to tensile stresses, increasing the concrete's strength) has an impact on the structure of the crushed interlock particles. Additionally, the angular particles of the crushed interlock material and their rough surface provide them with a stronger bond with cement or mortar than natural aggregate particles (gravel), changing the loading prior to the failure point. The specimens with crushed interlock wastes fail at modest applied loads, unlike the reference combination, which has no crushed interlock waste particles. In contrast, when the amount of crushed interlock waste particles is 100%, the compressive strength reduces (Fig. (7)).

The bond strength between the cement paste and the crushed interlock particles is negatively impacted by the surface of the particles (more angular and roughness). The specimens are weak under compression pressures because they contain a significant interfacial transition zone between cement paste and the crushed interlock waste particles in specimens with high crushed interlock waste percentages (100%).

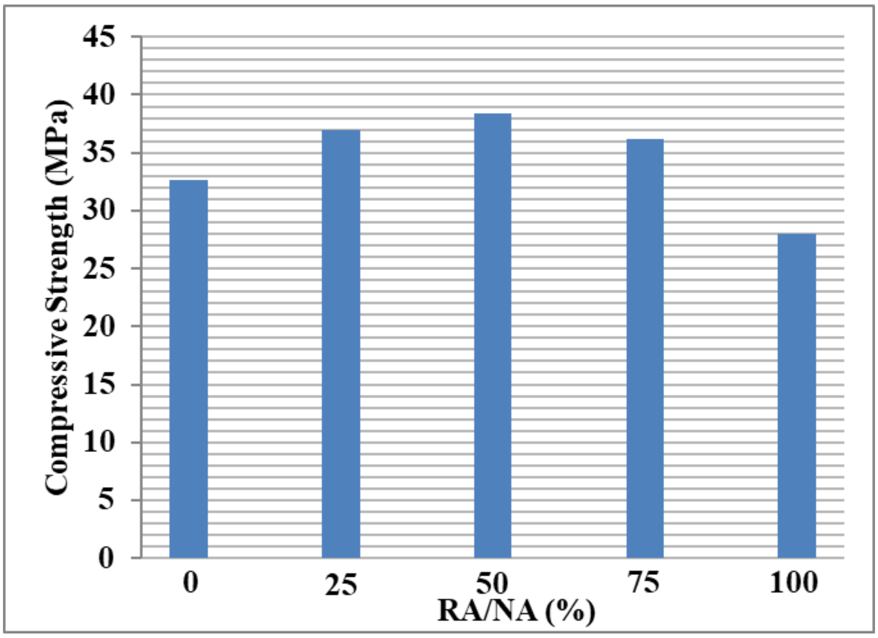

Figure 7. Compressive strength to (RA/NA) relationship at age 28 days.

3.5 Splitting tensile strength

A test was undertaken in accordance with ASTM C496 [25]. According to the results shown in Fig. (8), the splitting tensile strength reduces up to 100% as more crushed interlock waste particles are substituted. However, the decreasing values are 4 %, 17 %, and 25 % when crushed interlock replaced by 25 %, 50 %, and 75 % respectively at age 28 days. It is noted that crushed interlock particles have rough surfaces with high water absorption, which can lessen cement hydration. As a result, the strength is decreased because the boundary layer between the cement paste and the crushed interlock particles is larger than it is for natural aggregate particles. The results are in line with the findings by Nissren et al. [22].

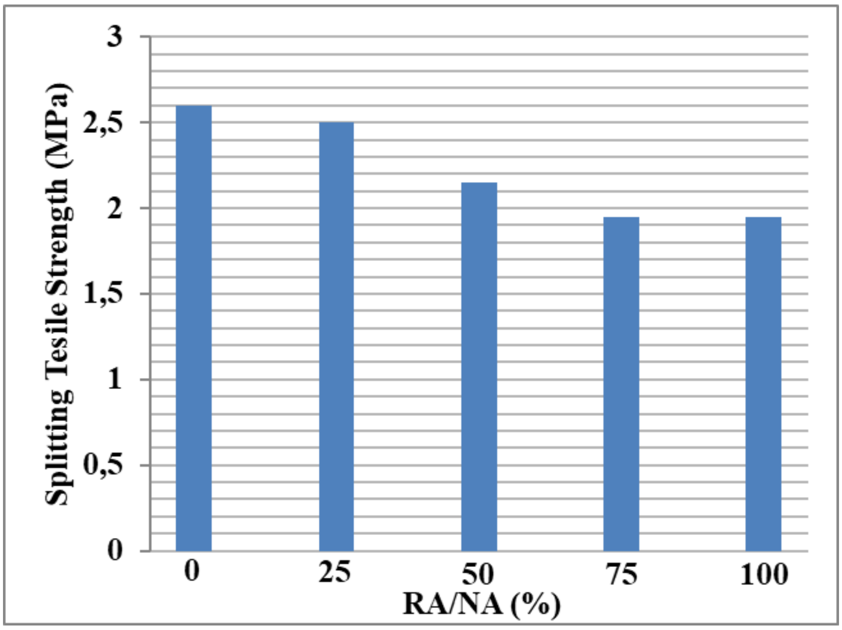

Figure 8. Splitting tensile strength to (RA/NA) relationship at age 28 days.

3.6 Flexural strength

The ASTM C293 [18] was followed in conducting the flexural strength test. The test is conducted using prism specimens with diameters of (100 x 100 x 500) mm. Specimens with crushed interlock replacement ratios between 25% and 100% decrease flexural strength. The high decay (20 %) is observed at the 100 % replacement percentage, i.e. In comparison to the reference specimens, specimens with crushed interlock waste replacement exhibit a drop in flexural strength, see Fig. (9). As per the standard BS 8500-1 (2006) [26], materials derived from reprocessed inorganic construction aggregate are referred to as recycled aggregates. Involvement of recycled coarse aggregates in concrete has been studied and has been shown to typically yield a decrease in flexural strength [27].

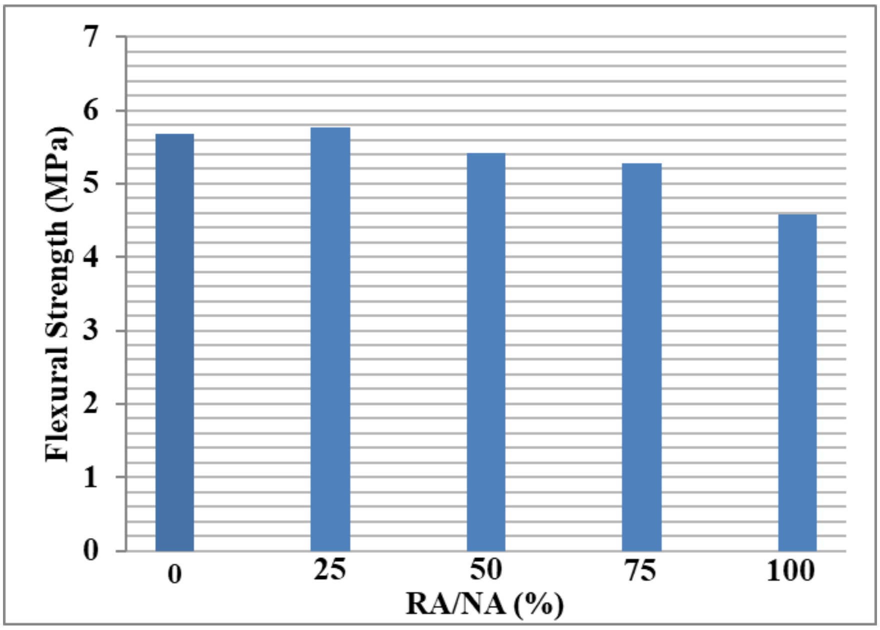

Figure 9. Flexural strength to (RA/NA) relationship at age 28 days.

4. Conclusion

The experiment's findings led to the following conclusions.

1. The workability of concrete drops with increasing the percentage of crushed interlock debris in the mix. The slump results were 2% and 12% lower for the 25% and 100%, respectively, crushed interlock replacement compared to the reference mix.
2. The amount of water taken up by a material increases as you have more crushed interlock, which can be as high as 54% when using only crushed interlocks as your aggregate for a concrete mix.
3. With increasing substitution, concrete's density drops off. Density decreases will be approximately 3% and 9% at 25% and 100% of substitutions, respectively.
4. Strength (compressive). The compressive strength is higher at 25%, 50%, and 75% substitutions than the control, respectively, by 13%, 18%, and 11%. The compressive strength decreases by 14% when substituting 100%.
5. Splitting tensile strength is generally decreased. The decreasing values are 4 %, 17 %, and 25 % when crushed interlock is replaced by 25 %, 50 %, and 75 % respectively.
6. The flexural strength, or measure of the ability of concrete to withstand bending, lower as the percentage of crushed interlock used in concrete enhance. Crushed interlock showed lower flexural strength than the reference mix (natural aggregates) regardless of the percentage replacements (25%, 50%, 75%, or 100%).

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