Concrete with Recycled Fine Aggregate (RFA) and Manufactured Sand (MS): Compressive Strength and Cost

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Research Article

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Abstract

Ethiopia's construction industry is developing at an unprecedented rate. Concrete production necessitates a large number of natural resources in this developing industry. River sand is commonly utilized as a fine aggregate in concrete compositions. However, due to a wide range of variability, cost, and quality issues, sand availability in the burgeoning Ethiopian construction industry would be a concern. Keeping this in mind, numerous structures are being demolished and replaced by new ones as part of the present modernization and expansion of cities. There are two issues with the generated concrete wastes as a result of that demolition process: on the one hand, environmental degradation caused by the materials extraction activity, and on the other hand, damped demolished wastes. As a result, the physical properties of fine aggregates are studied in this study, as well as the strength and cost of concrete produced by partially substituting sand with Reused Fine Aggregate (RFA) and Manufactured Sand (MS). Compressive strength tests were performed, and the findings showed that concrete containing RFA and MS as sand substitute has a higher compressive strength than standard concrete. Concrete that replaces all of the sand with RFA and FMS is a cost-effective mix that can save up to 2.41 percent of the overall cost of the concrete.

1 Introduction

Because of Ethiopia's rapid urbanization, industrialization, and economic development, the building industry is expanding dramatically, resulting in a rise in the consumption of construction materials. Due to the fact that natural sand is not readily available in most places of Ethiopia, this has resulted in rapid depletion of natural sand and scarcity of sand of good quality. It must be carried over a considerable distance, or contractors will use whatever sand is available, which may or may not satisfy the required specifications [1]

Due to a wide range of unpredictability, cost, and quality issues, sand availability in the rising Ethiopian construction industry will be a concern [2]. The building business, on the other hand, is one of the industries that contributes a significant amount of garbage to the environment. The amount of garbage generated by the building sector in developing countries is tremendous, and due to inadequate management procedures, these waste materials are deposited directly into landfills, causing contamination. However, by repurposing garbage for different purposes, the environmental impact can be decreased. Finding all options and prospects for minimizing the waste products of work areas must be a primary job if the environment is to be better preserved for sustainable growth [3].

In today's world, construction and demolition waste recycling is critical for long-term development. Because of the need for sustainability and the scarcity of natural resources, the United States, Japan, and parts of western regulations have considered the use of recycled and secondary aggregates, such as crushed concrete, asphalt, and industrial byproducts, and have put in place enough regulations to ensure that recycled and secondary aggregates account for more than 10% of total aggregate use. Because recycled materials take energy to manufacture, they may not necessarily be more sustainable. As a result, it may be necessary to assess the optimal Factory-made sand as a substitute for river sand has shown to be useful and is now widely used around the world. FMS is made by crushing larger quarry stones into a specific sand size, and its chemical and physical features, such as color, size, shape, and surface roughness, are dependent on the type of stone and its source. Manufactured sand has shown to be a viable alternative to natural sand, and it has become critical in meeting the technical, commercial, and environmental criteria of concrete manufacturing [4].

The uneven surface, irregular particle form, angular edges, increased roundness, length-width ratio, and mineralogy distinguish FMS from natural sand [5]. As a result, it is critical to examine MS as an alternative material to Natural River sand in order to alleviate the problem of Natural River sand depletion and shortages in Ethiopia.

The most commonly used material for wall building in Ethiopia is HCB; nevertheless, it might be fractured on production or construction sites during loading and unloading, resulting in waste. These wastes are gathered in a site with varying sizes and quantities and disposed of in a landfill. Because of their abundance in both demolished and construction/production sites, recycling of wall materials (HCB wastes) is critical [6].

Due to the increasing demand for buildings and other infrastructure in Gondar City, high-quality sand is not always available and must be carried over vast distances. Increased demand for river sand results in a cost increase, which poses a problem to the business because it raises construction costs. Furthermore, river sand may be a concern not just in terms of cost, but also in terms of availability and quality. Because its resource will be diminished over time, the river sand's long-term viability is jeopardized. As a result, an alternative for HCB waste must be recycled. As a result, rather than creating aggregates from virgin sources, HCB wastes and FMS from local crusher facilities are more than adequate. As a result, the research's major goal is to evaluate the and cost of concrete produced by partially replacing river sand with a 1:1 mix of reused sand from demolition HCB wastes and factory-made sand in Gondar area.

1.1 Research Questions

- What are the best sand replacement rates for achieving the desired concrete compressive strength using combination materials?
- Which concrete, combined materials concrete or river sand concrete, is the most cost-effective?

2 Experimental Investigation

The goal of this study was to test the strength and cost of C-25 concrete by partially replacing sand with destroyed reused fine aggregates and FMS. The investigation's materials are explained in terms of their source and physical qualities. In all of the test mixes, the amounts of cement, water, and coarse aggregate were kept constant, while the amount of FMS, RFA, and river sand was varied.

The study's data was gathered from both primary and secondary sources. The results of laboratory tests were recorded as primary sources of data for this investigation. During the literature evaluation, secondary data for this study was gathered from various journals, books, and websites.

2.1 Materials

Cement

All of the trial mixes used the same type of cement, OPC with a grade of 42.5R, and the amount used each mix was kept constant.

Sand

Locally accessible as a fine aggregate, ASTM-compliant river sand is employed.

Reused fine aggregates (Demolished HCB wastes)

River sand was substituted with fine aggregate left over after the HCB's demolition. The HCBs were found in Gondar, Camelot's capital, in demolished residential buildings. Separating the demolished HCB from disposal sites, removing undesired attachments on HCB such as ceramics from bathroom and shower rooms, and breaking the blocks to the required sizes with a rock hammer were all used to repurpose the demolished HCB for fine aggregates. The crushed aggregates were evaluated using traditional sieve analysis, and fine aggregates were defined as those that passed the 4.75mm sieve size. Gypsum, clay, wood, ceramics, and biological components are among the RFA's impurities. Screening, handpicking, or water flotation, as well as washing, were used to eliminate these impurities from RFA. To determine the quality of recycled fine aggregate, ASTM standard tests are used.

Manufactured sand (MS)

To maintain material consistency in aggregates, every factory-made sand was sourced from the same basaltic stone crushing plant.

Coarse Aggregates

The physical properties of coarse aggregate based on the ASTM C 136-96a, was evaluated as follows:

Coarse aggregate Size 25mm

Bulk Specific Gravity 2.84

Specific Gravity (SSD). 2.86

Bulk Unit Weight 1625 Kg/m3

Compacted Unit Weight 1712 Kg/m3

Water absorption 0.61%

Moisture Content 0.81%

Water

All concrete mix is made with tap water provided by the Gondar water supply and sewage authority.

Mix Design

The reference or control mix (100 percent sand, 0 percent RFA, and 0 percent MS) was utilized to make different RFA and MS mixes with a constant water-cement ratio of 0.491 and a slump range of 75-100mm.Trial mix and final mix based on the results of the trial batch, adjustments and improvements to the mix's replacement rates were made.

2.2 Cost calculation

The material cost of produced concrete per unit volume was calculated based on the current base price of materials from the city and various considerations of HCB wastes use in current construction sites such as a selected material and with a mix of other materials used as bedding materials for small structures such as crossing ditches and walkways.

As a result, the cost effectiveness of concrete can be measured by comparing the cost of the reference or control mix to the cost of the local market within the city.

- The volume of HCB wastes generated from a given volume of selected materials and bedding is estimated to be 30%
- The cost of washing and screening is calculated at 25 Birr per cubic meter
- The cost of crushing is calculated at 50 Birr per cubic meter (machine based)

3 Results And Discussion

2.3 Hardened Concrete Property

To assess the compressive strength of concrete mixes, 99 (150mm150mm150mm) cube molds were utilized and tested after 3, 7, and 28 days according to the BS-1881-116 standard.

The use of RFA & MS as a sand replacement increases the mechanical properties of concrete after 3, 7, and 28 days of curing up to 70% RFA & MS content. However, even if 100 percent of the sand is replaced with both components, the compressive strength is unaffected. At all testing dates, increasing the natural sand replacement rate had a favorable influence on the concrete's compressive strength. Because of the angular and rough surface texture of manufactured sand, as well as proper gradation and screening or washing of RFA, increased the bond between sand particles. Another important point is that increased strength is associated with a reduction in the effective water-cement ratio, which is due to the high-water demand of both materials.

Because of different impurities on recycled fine aggregates like some finishing materials like gypsum, quartz, and others, and the adhered mortar makes the transitional zone weak because this zone is composed of the recycled fine aggregate and the cement matrix, and this portion is the weakest phase in recycled fine aggregate, the compressive strength results start to decline but still above the control mix. And under MS, due to the existence of high micro fines content, which may affect the manufactured sand rough surface and reduce friction between the manufactured sand particles, the compressive strength of concrete begins to drop due to the influence of those features of both materials. As a result, a 70 percent replacement of sand using a combination of recycled fine aggregates and manufactured sand is the best option (35 percent RFA & 35 percent MS).

2.4 Cost Analysis

The effect of partial replacement of sand by recycled fine aggregates and manufactured sand on the cost of concrete, which is expressed by cost per cubic meter of concrete, is assessed based on the material prices collected from most common sources and suppliers within and around Gondar city. The cost comparison only considers the cost of material, transportation and other costs such as labor cost, equipment cost, profit, maintenance, and overhead costs assumed to be the same. The unit cost of cement is taken as the average cost of *Dangote OPC, Messbo OPC and Derba OPC*, which is mostly, used cement in Gondar and the cost of manufactured sand is average cost of three supplier's plant taken as the unit cost. Generally, the price of ingredients was collected from local suppliers.

According to the cost study, when the percentage replacement rate of RFA and MS increases, the cost decreases. The reason for this is that both materials are abundant in Gondar. As a result of the investigation, mix 11 has a cost-effective and economic advantage over the reference mix.

4 Conclusions

The impact of partially replacing natural sand with a combination of recycled fine aggregates and manufactured sand on the compressive strength and cost of C-25 concrete was researched in the preceding sections, and the following conclusions are derived from the data.

- The compressive strength of concrete can be improved by 21.69 percent by partially replacing sand with RFA and MS up to 70%. As a result, a combination of a thoroughly washed, screened RFA and a well graded MS can be used to replace natural sand up to 70% of the time. This could result in a 70% reduction in the use of river sand.
- The cost research also shows that completely substituting sand with RFA and MS can save up to 2.41 percent on overall concrete costs when compared to traditional concrete.

Declarations

Competing interests

It has no any funding relationship with any organization. Saying this, the document is non-reported.

Abbreviations

ACI	American Code Institute
ASTM	American Standard of Testing Material
BS	British Standard
C&D	Construction and Demolition
MS	Manufactured Sand
NS	Natural Sand
HCB	Hallow Concrete Block
RHCB	Recycled Hallow Concrete Block
RFA	Recycled Fine Aggregates
RS	River Sand
OPC	Ordinary Portland cement
PPC	Portland Pozzolana Cement
ES	Ethiopia Standard
IS	Indian Standard
W/C	Water to Cement
AASHTO	American Association of state highway and transport officials
FM	Fineness Modules

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Tables

Table 1: physical properties of river sand, RFA, & FMS after washing

	FM	Unit weight		Moisture content	Absorption	Silt Cont.	Specific gravity		
		Bulk	**compacted**				**bulk**	**SSD**	**Apparent.**
		Kg/ m3	**Kg/ m3**	**(%)**	**(%)**	**(%)**			
Sand	2.53	1569	1702	1.1	2.29	3.6	2.61	2.70	2.88
RFA	2.60	1410	1551	1.2	3.95	4.7	2.67	2.77	2.98
FMS	2.73	1592	1373	0.2	1.83	2.1	2.76	2.81	2.91

Table 2: Proportioning of specimen for trial mix

Mix No	River Sand (%)	RFA (%)	FMS (%)	Per	Cement	Water	Coarse Aggregates	Sand	RFA	FMS
1	100	0	0	m3	394	182.8	1141.8	716.03	0	0
2	80	10	10	m3	394	187.2	1136.9	509.6	110.5	113.1
3	60	20	20	m3	394	193.82	1133.6	437.6	147.7	151.1
4	40	30	30	m3	394	197.1	1128.7	293.7	222.9	228.2
5	30	35	35	m3	394	199.7	1123.8	221.6	261.7	267.8
6	20	40	40	m3	394	202.2	1123.8	147.7	299.05	306.1
7	0	50	50	m3	394	207.2	1120.5	0	375.4	384.2

Table 3: Proportioning of specimen for final mix

Mix No	Sand (%)	RFA (%)	MS (%)	Cement (m3)	Water (m3)	Coarse Aggregates (m3)	Sand (m3)	RFA (m3)	MS (m3)
1	100	0	0	394	182.41	1141.8	716.03	0	0
2	90	5	5	394	184.8	1140.2	651.1	36.6	37.5
3	80	10	10	394	187.2	1136.9	581.1	73.5	75.3
4	70	15	15	394	189.7	1135.2	509.6	110.5	113.1
5	60	20	20	394	193.82	1133.6	437.6	147.7	151.1
6	50	25	25	394	194.61	1132	365.5	185	189.3
7	40	30	30	394	197.1	1128.7	293.7	222.9	228.2
8	30	35	35	394	199.7	1123.8	221.6	261.7	267.8
9	20	40	40	394	202.2	1123.8	147.7	299.05	306.1
10	10	45	45	394	204.7	1122.15	74.06	337.2	345.09
11	0	50	50	394	207.2	1120.5	0	375.4	384.2

Table 4: compressive strength results

MIX 1	MIX 2	MIX 3	MIX 4	MIX 5	MIX 6	MIX 7	MIX 8	MIX 9	MIX 10	MIX 11
3 Days (MPa)										
14.36	14.25	14.79	14.77	16.05	17.24	17.97	18.12	18.44	18.75	18.76
7 Days (MPa)										
20.72	21.89	22.51	22.40	23.73	24.44	25.21	25.46	25.18	25.09	24.44
28 Days (MPa)										
34.06	34.97	35.06	36.03	37.28	39.38	40.00	41.45	38.31	36.61	35.63

Figures

Figure 1

River sand

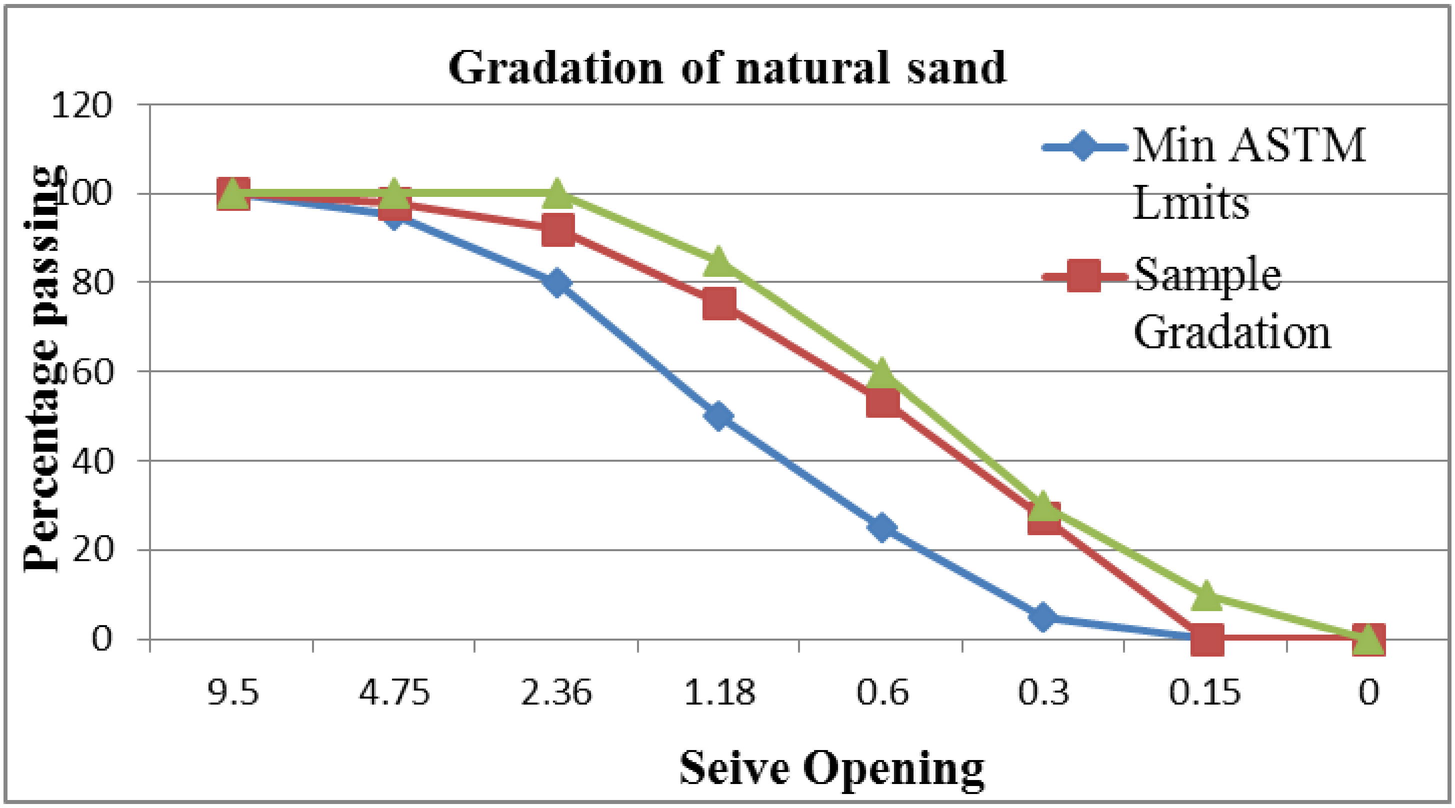

Figure 2

Gradation of River sand

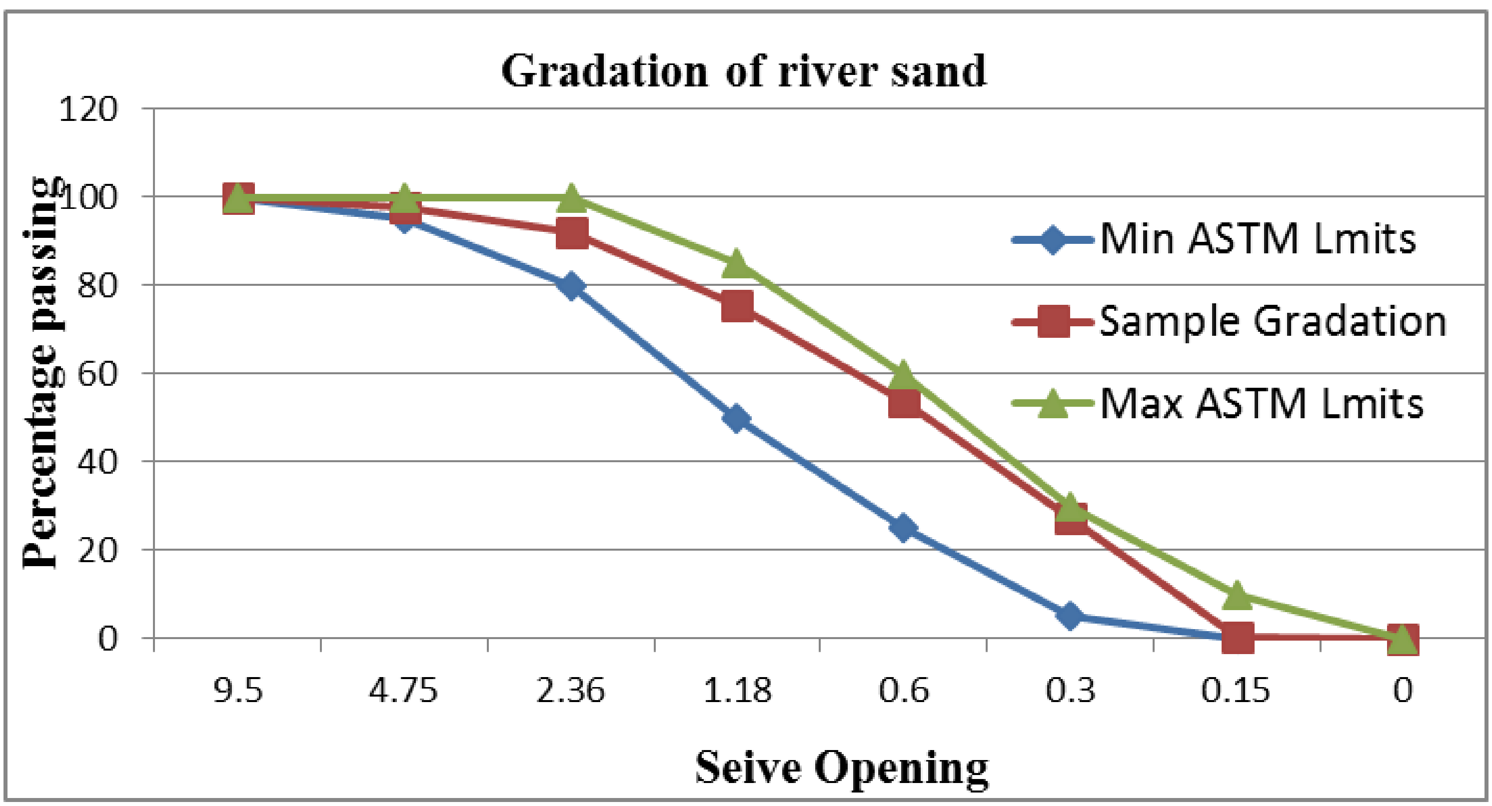

Figure 3

Gradation of reused fine aggregates

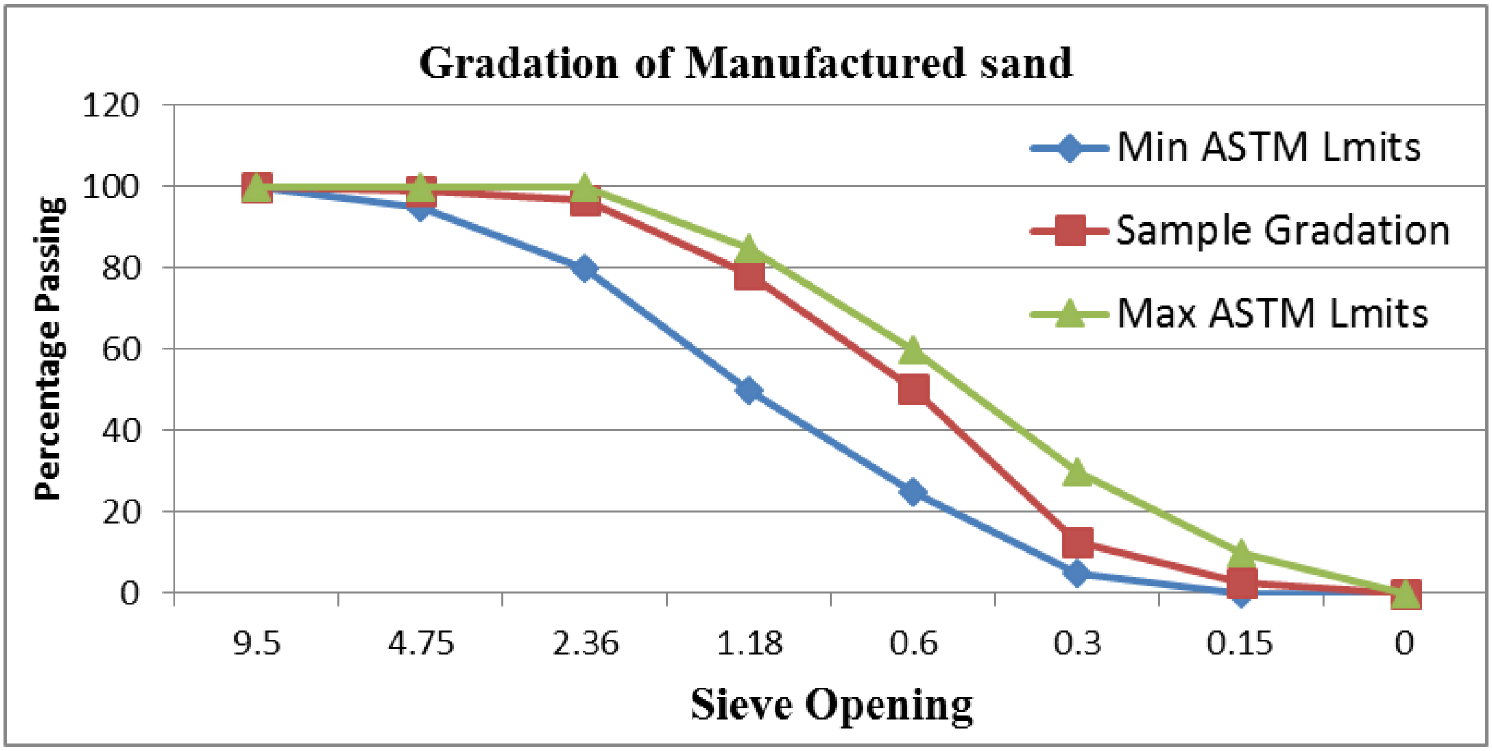

Figure 4

Gradation of factory-made sand

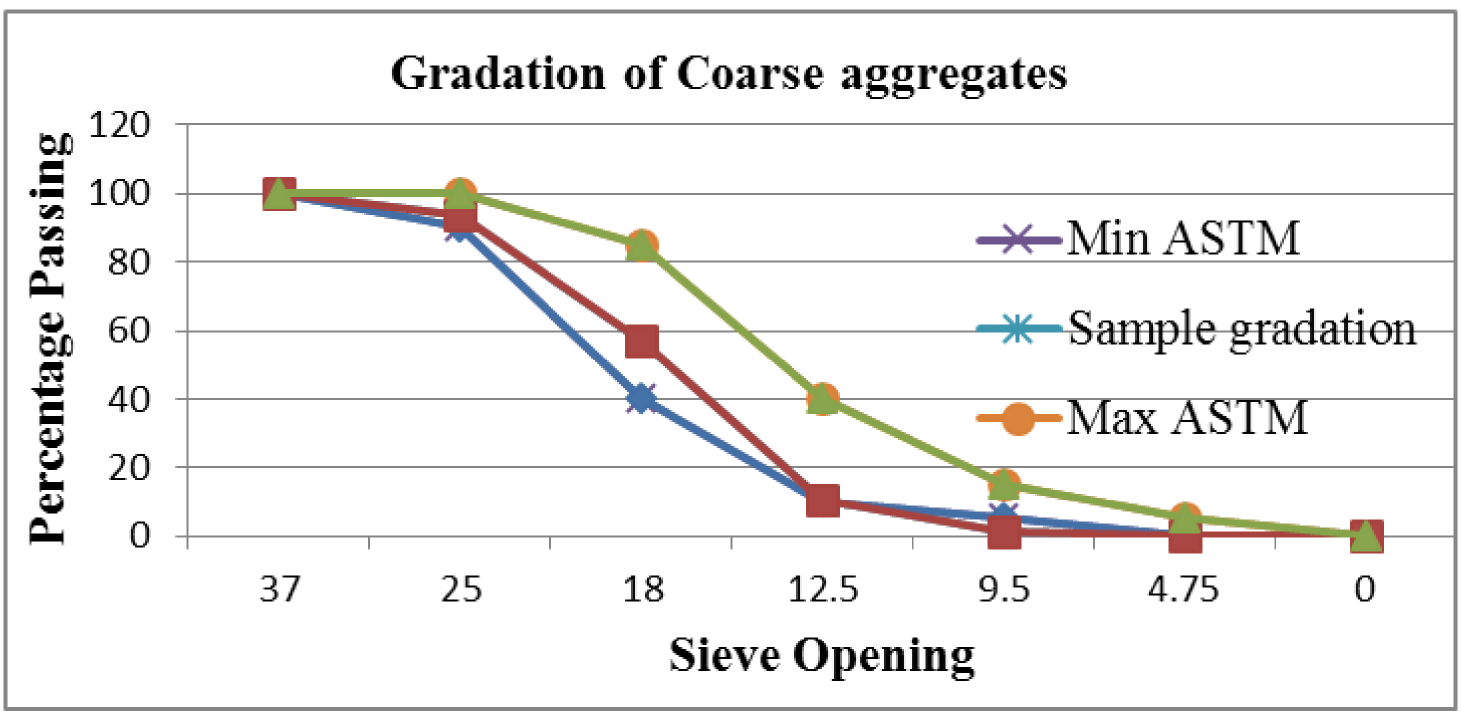

Figure 5

Gradation of coarse Aggregates

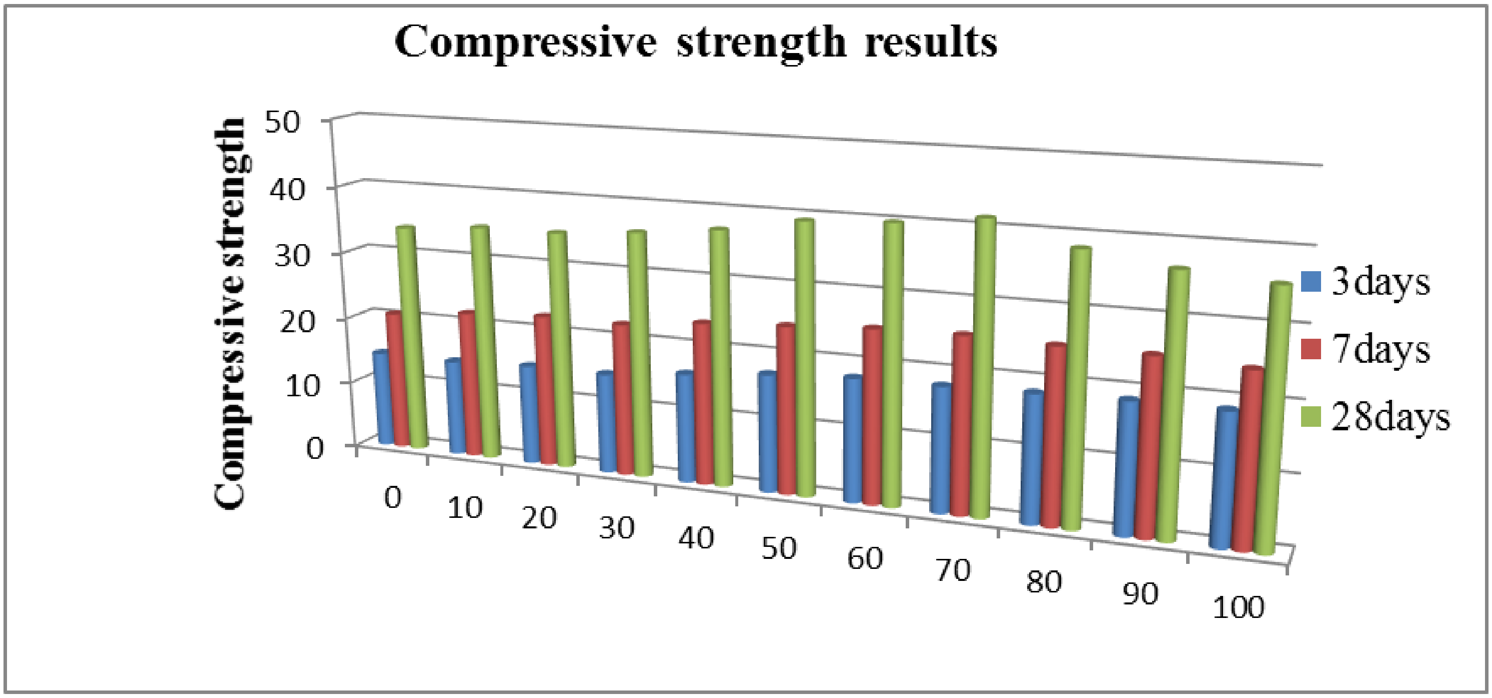

Figure 6

Compressive results of final mix

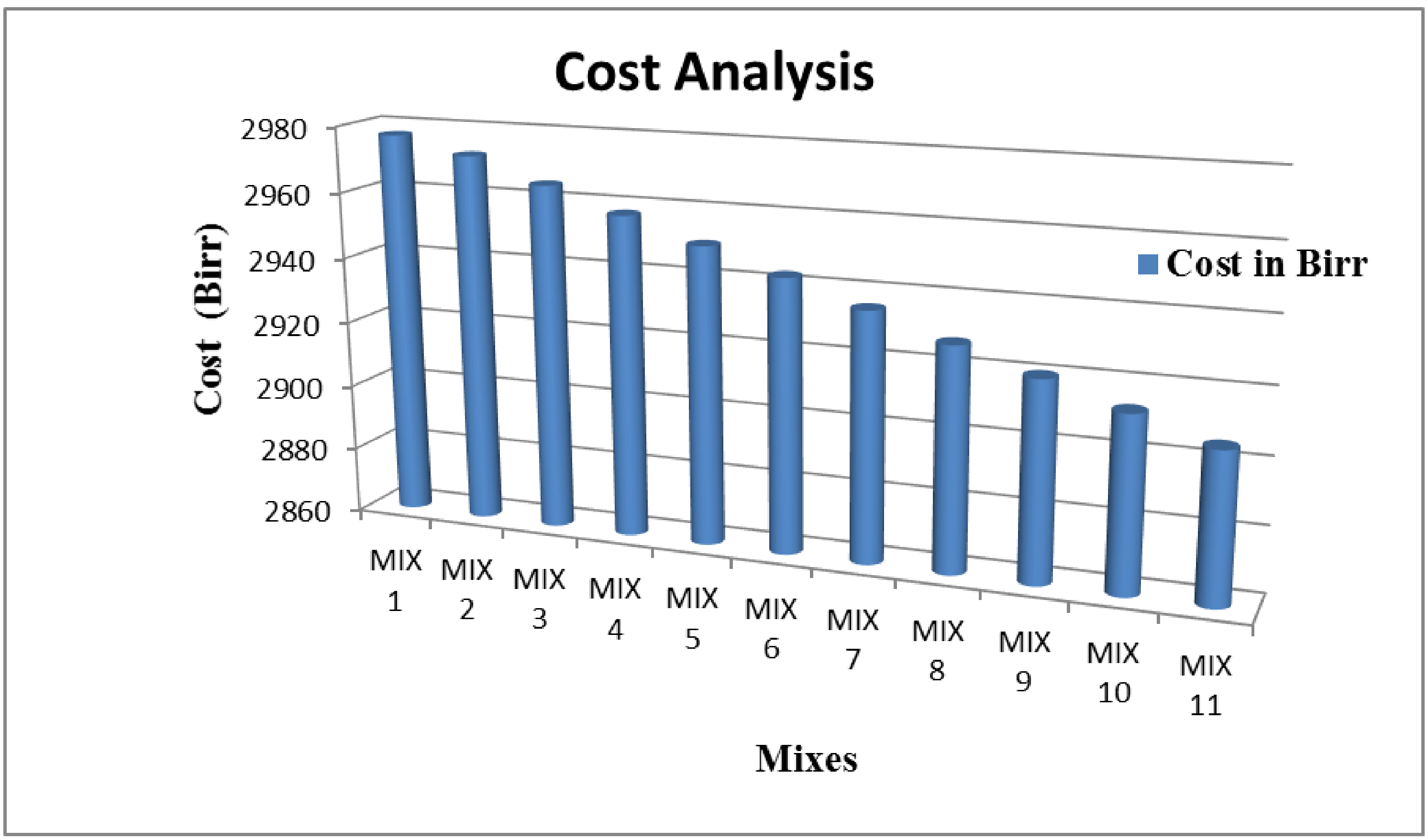

Figure 7