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The empirical study of gradation of crushed sand concrete properties using six sigma DMAIC methodology

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KEYWORDS

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ABSTRACT

Fine aggregate plays a key role as a filler material in concrete’s fresh and hardened properties. Generally, in Portland cement concrete aggregate occupies 70-85% by weight and 60-70% by mass. In Pakistan, Lawrence pur the sand as the only sand that meets the ASTM standards. But due to heavy transportation costs, it is not cost-effective to use in most parts of the country. The tests were carried out in accordance with ASTM standards, and the concrete mix designed with three water-cement ratios of 0.40,0.45, and 0.50 called for a mixing procedure. At 28 days of curing, an M30 concrete mix comprising five control mixes including parent concrete was evaluated and compared to parent concrete. This experimental work aimed to enhance the fresh and hardened properties of concrete such as the workability of concrete mix, compressive, and flexural strengths by using locally available Jhelum River sand gradation crushed sand (passing sieve #4, the waste product of Sargodha coarse aggregate), s a fine aggregate material. Using six sigma DMAIC Methodology 9 defects in the Jhelum River sand and control mix have been identified and corrective measures were taken to improve the quality of the concrete mix. The results derived from this experimental work show that adding 50% crushed sand in Jhelum River sand increases compressive strength by 27% and flexural strength by 20% which makes it according to ASTM Standards. The use of crushed sand as an alternative to natural river sand efficient and safe material. This control mix also reduces the construction cost by 10% in comparison to lawerancepur sand.

1. Introduction

Generally, aggregate occupies about 70-85% by weight and 60-70% by volume of the portion of Portland cement concrete. The overall performance of concrete is affected directly by the aggregate properties that we are using in the concrete mixture at the start stage and hardened stage [1]. The aggregate has significant impacts on the concrete characters and among these, there can also be many characters that have a gradation notion of aggregates frequently recognized as distribution of the measurement of the particles of the mixture to provide success of the homes Concrete’s workability, strength, durability, and financial system are all influenced by the aid of combination qualities. Aggregate’s thermic, physically and chemical elements affect the overall performance of concrete, it is now not inner [2]. Sand gradation or particle dimension distribution has an impact on concrete properties such as packing density, void content, workability, and strength [3]. The sources, size, shape, mass, consistency, and different coarse aggregate characteristics determine their mineralogical, physical, and mechanical properties. The compressive and flexural strength, workability, and sturdiness of concrete are all affected by variations in aggregate properties. The strength, quality, and overall performance of concrete in both the fresh and hardened stages are significantly influenced by the type of aggregate used in the mixture[4]. Divya Haritha and her colleagues compared the use of crushed rock as fine aggregates to excessive strength concrete with the use of ordinary fine aggregate and determined that crushed rock as a fine mixture increases the compressive strength of concrete. At what time the fine mixture is substituted with crushed rock, the split tensile strength of the concrete increases[5]. The Six Sigma technique may assist in identifying and eliminating defects, setting performance targets, increasing customer value, and achieving strategic objectives. Six Sigma is implemented in a methodical manner using the "five-stage DMAIC approach (Define- Measure- Analyze- Improve-and-Control)" [6]. Several academics have utilized this technique in their studies to enhance operations such as concrete block production, a flywheel manufacturer's sand-casting process, and the quality valuation of ready-mix tangible plants[7] [8].

2. Literature Review

The research carried out by [9] depicted how both fine, as well as Coarse aggregates having size distribution affect the hardened concrete properties mainly compressive Strength. Aggregate gradation optimization is important as proper aggregate grading gives maximum packing Density/ dense concrete of combined aggregate which results in decrease in cement paste quantity requirement and fills the spaces within aggregate. Twelve mixes were prepared using three different types of fine aggregates (FM: 2.0, 2.5. 3.0) and four type of coarse aggregates (FM: 6.0, 6.5, 7.0 and 7.5). Increase of FM of both fine aggregate and also coarse aggregate resulted in increase of compressive strength and an Extreme value of compressive strength stood achieved when FM for both aggregates was the highest [5].Variation of concrete Strength (Compressive) with the change in FM of Both Aggregates. Previous research studies have shown that the quantity of natural sand required in concrete is lower compared to crushed sand. Additionally, the cost of crushed sand is 75% less than that of natural sand. These findings have prompted countries to modify their specifications, particularly in allowing the use of sand in crushed form for specific mixtures.

Sanjay Mundra in 2016 conducted research on the usage of crushed rock sand as a viable and cost-effective alternative to natural river sand. This study demonstrated that crushed stone sand is suitable for replacing river sand in concrete applications. The results of this research have influenced countries to revise their specifications, allowing for the use of sand in crushed form in certain mixtures. These specifications include standards such as AS2758.1 (1998), BSI EN 12620 (2008), JISA5005 (2009), and ASTMC33/C33M (2013), which are designed to accommodate the use of sand in crushed form.

Another study focused on the impact of partially substituting natural sand with Crushed Rock Dust (CRP) on the physical characteristics of mortar and concrete. In the first stage of the study, different percentages of partial replacement (20%, 40%, 60%, 80%, and 100%) were evaluated, and the strength of the mortar was assessed. In the second stage, particles smaller than 150 microns were separated from the CRP, resulting in Conditioned Crushed Rock Powder (CCRP). CCRP was then used as a replacement for sand in cement mortar. Based on these previous works, it has been established that crushed rock sand and CRP can improve the properties of concrete and mortar. Furthermore, the cost advantages of using crushed sand have been demonstrated, making it an attractive alternative to natural sand. In our current study, we cast cubes of M20, M30, and M40 grade concrete mixes and subjected them to curing for 7, 14, and 28 days. Through this experimentation, we aim to further evaluate the improvements in concrete properties when utilizing crushed sand [4]. In the third stage, concrete specimens of three different grades (M20, M30, and M40) were cast with CRP replacing 20%, 30% and 40% of the sand. Concrete workability was maintained at around 100mm for M20 and 70mm for M30 grades, respectively[10] . However super plasticizer was utilized with proper Dosage only for M40 concrete grade to achieve a slump of about 70mm due to the fact that the mix's workability of mix below acceptable standards. [11]. "Experiments was accepted out to investigate the viability of by means of stone dust as a whole auxiliary for natural sand. Cement concrete cubes of grades M20 and M25 were premeditated and tested for strength and workability using varying amounts of fine aggregates. According to the study, a mix ratio of 1:1.5:3 provided the best strength. The compressive strength increases as the proportion of stone dust increases, as long as the amount of replacement does not exceed 50%" [12], [13].Crushed and self-compacting concrete has higher shear strength than river sand self-compacting concrete with the same w/c ratio and amount of shear reinforcement. Crushed and self-compacting concrete may be able to carry more weight with less deflection than self-compacting river sand concrete"[3]. Crushed stone sand has a favorable influence on compressive, flexural, and tensile strength when used as a fine aggregate in concrete. CSS is ideally suited to normal-strength concrete, providing superior strength and lowering costs over standard sand. As the ratio of crushed stone sand replaced increases, the workability of concrete decreases. The result shows that when CSS is replaced as fine aggregate, the mechanical characteristics of concrete increase up to 20% and then decrease at 100% replacement[14]. According to the DMAIC methodology, the data analysis and results section in this paper are alienated into five stages [15] . The goal of this research is to help replace natural Jhelum River Sand with crushed sand with several concrete mixes for cost savings in Pakistan on the one hand and improving the properties of the concrete formed on the other.

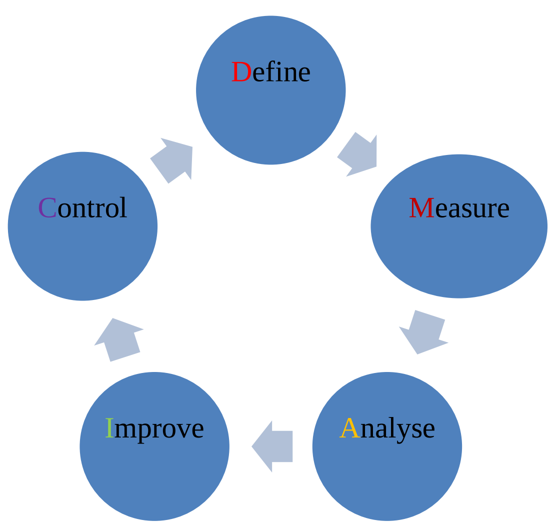

Fig. 1 Method stages of six sigma [6]

3. Research Methodology and Laboratory Investigation

The study sought to identify the optimum concrete mix manufactured from crushed sand derived by passing sieve #4, a waste product of Sargodha coarse aggregate. The general framework structure is based on the DMAIC approach developed by Six Sigma. To achieve the research objectives, the following methodology was adopted.

Step No.1

A detailed study and comparison of National / International available literature on the proposed subject was carried out.

Step No.2

Constituents of Normal Concrete were selected to ascertain a conventionally used concrete strength (fc 30 MPa).

Step No.3

Physical properties of all the selected material i.e., cement sand coarse aggregates were determined according to the ASTM standards guidelines, which include Fineness Modulus (FM), and specific gravity, water absorption, and bulk density.

Step No.4

Keeping the same percentage of all other constituents, w/c ratio, and mix proportion, a replacement percentage of fine aggregate with crushed sand (crushed sand) was selected, satisfying the requirements of FM and grading of ASTM 33 % ASTM C 136 respectively and concrete specimens were cast on that mix proportion.

3.1 Design/Target strength

Depending on the expected variation in strength, the mix design's target strength (fc') is greater than the prescribed minimum 28-day cylinder strength (fc'). If previous data is unavailable, the required average compressive strength can be calculated using the ACI Code as follows:

fc' ≥ fc' + 8.5 MPa for fc': 30 MPa

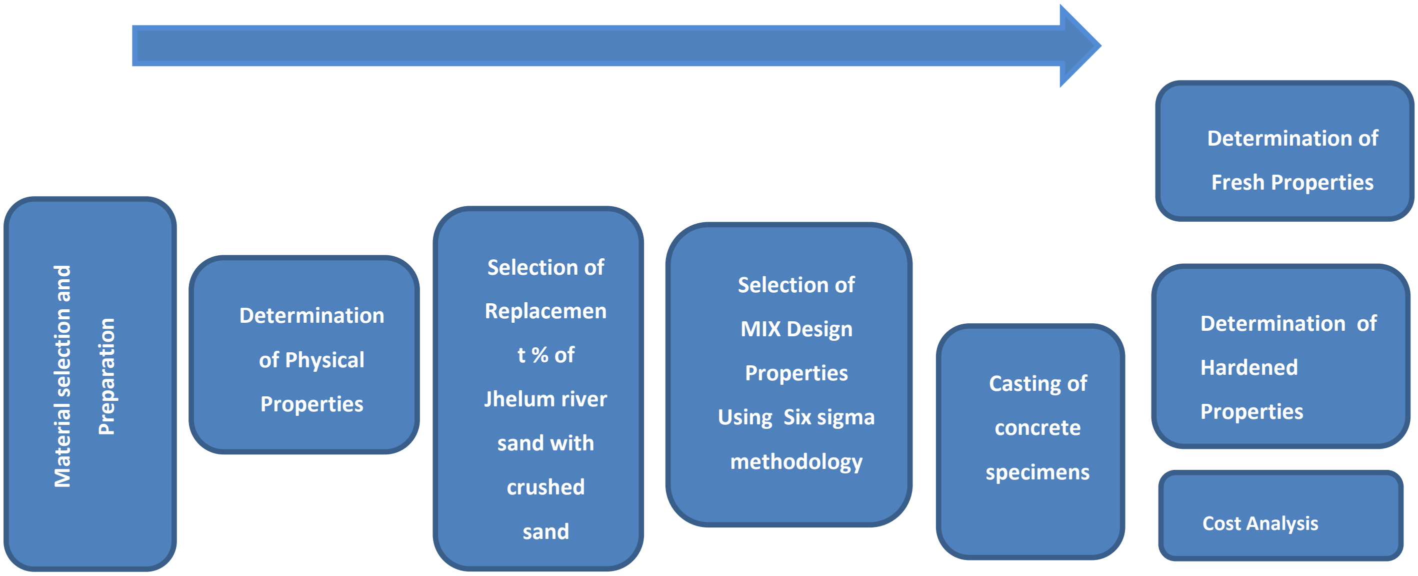

Fig. 2. Methodology adopted in flow chart

4. Data Analysis and Results

4.1 Define

The DMAIC technique begins with a definition. At this point, the problem has been recognized, and response variables have been put up to study it. The stage also demonstrates the importance of this research.

4.1.1 The problem

Aggregates are made from regionally accessible sand in Pakistan (Lawrencpur, Jhelum River Sands). Only Lawerancepur sand meets the standard's requirement, but it is expensive due to high transportation costs. The FM of Lawrencpur sand is greater than 2. The goal of this study is to improve the gradation of regionally accessible Jhelum River Sands in order to make concrete mixes more cost-effective, have higher properties, and meet ASTM standards. In this study, the gradation of Jhelum River Sand is improved by partially replacing its proportion with crushed sand (residual material of Sargodha gravels, passing sieve # 4). This study is being conducted on M30- concrete made gradation with the goal of determining an optimum state that will improve the quality of Jhelum River Sand.

Table 1

SIPOC

Supplying	Inputs	Process	Output	Customer
Raw Material	● Cement ● Fine aggregates (Crushed sand and Jhelum River sand) ● Coarse aggregates ● (Sargodha crush) ● Water	Follow up all steps of methodology stages	Mix Designed concrete	Researcher

4.1.2 Research significance

This research will be significant in the following aspects of the construction industry of Pakistan. This study also will be providing better workability and more compressive and flexural strength of concrete. It will cost-effective and also extend the knowledge of coarse aggregate as it relates to civil engineering works.

4.2 Measure

The Measure stage is in charge of establishing the procedure and researching the materials used in the production of concrete for this study, as the problem was defined in the previous stage.

4.2.1 Materials

The raw materials used in this study are cement, fine (crushed/Jhelum River Sand) aggregate, water, and Sargodha crush as coarse aggregate. Concrete was brought to save money. For experimentation, crushed sand material is sieved #4 according to ASTM standards. In the Analyze stage, their properties and test results are explained.

4.2.2 Cement

In the local market, there is a wide range of cement brands available. To ensure consistency in the age and source of cement, FAUJI CEMENT Company was selected for this study, in accordance with the requirements of ASTM C-150. This choice was made to maintain uniformity in the concrete specimens, allowing for the examination of the effects of various fine aggregate replacements, with or without the use of crushed sand. All other construction materials were kept constant throughout the study. The properties of FAUJI CEMENT utilized in this research are presented in the table below.

Table 2

Physical properties of FAUJI CEMENT

Properties	Value
Value of consistency	24%
Setting Time of cement (Initial)	27 Minutes
Setting Time of Cement (Final)	134 Minutes
Expansion (Soundness Value)	8mm
Compressive Strength (3day)	2415 Psi
Compressive Strength (7 days)	3714 Psi
Fineness of cement, %Retained on sieve #200	7%

4.2.3 Fine aggregates

Fine aggregates are chemically inert and structurally sound filler materials used in concrete or cement paste for the purpose to fill the voids within the aggregate's particles.

Jhelum River Sand: It is quite good but may be contaminated with mud or mixed with clay, silt, or mica.

4.2.4 Crushed sand

In some areas where natural sand is not available or freight charges make it uneconomical, stones can be crushed and used as sand. The objective of the research is to enhance the gradation of locally available Jhelum River Sand because only Lawrencpur sand satisfies the ASTM C 33 standards Fineness Modulus requirement.

4.2.5 Coarse Aggregates

Coarse aggregate is the largest portion and main load-bearing component in a concrete mixture that affects the strength of concrete. However, in this research program, its source is kept constant and locally available coarse aggregate i.e., Sargodha coarse aggregate was used. Aggregates were properly sieved on sieve ¾" and # 4 sieves. Water plays an active role in the chemical reaction with ordinary Portland cement.

4.2.6 Water

Water contributes to the chemical interaction with cement. The amount of water used should be just enough to hydrate and work the concrete. Potable water devoid of floating and dissolved contaminants was utilized in this investigation.

4.2.7 Water cement ratio:

In this study, three type water/cement ratios are considered: 0.40, 0.45, and 0.50.

4.3 Concrete Mix and Specimen Preparation

For the study, mix design calculations were performed to determine the mix proportion of each type of concrete mix, and an M30 mix was prepared with three different w/c ratios. Concrete is prepared according to ASTM standards, and each mix was cast to test the compressive strength and modulus of rupture. The Analyze stage displays test results.

Table 3

Mix Design

S.	Mix Types	
1	CM-1	Lawerancepur Sand (LS)
2	CM-2	Jhelum River Sand (RS)
3	CM-3	30% Crushed Sand and 70% Jhelum River Sand(3CS+7RS)
4	CM-4	40% Crushed Sand and 60% Jhelum River Sand(4CS+6RS)
5	CM-5	50% Crushed Sand and 50% Jhelum River Sand(5CS+5RS)

4.4 Analyze and Results Stage

4.4.1 Properties (Physical) of Concrete

Properties of both fine and coarse aggregates were determined first before preparing concrete samples according to the procedures mentioned in the ASTM standards. These properties include Bulk Density, Fineness Modulus, Water Absorption, and Specific

Gravity and these are presented in Table 4 and 5 representing different ASTM Standards followed for determining these properties of both aggregates (fine and coarse).

Table 4

Properties of both fine and coarse aggregates

Properties	ASTM Standard
Sieve analysis	ASTM (C-136)
Bulk Density	ASTM (C-29)
Sp. Gravity and Water Absorption for Fine Aggregates	ASTM (C-128)
Sp. Gravity and Water Absorption for Coarse Aggregates	ASTM (C-127)

4.4.2 Fresh and hardened concrete properties

Tests performed on hardened concrete specimens to determine hardened state concrete properties were carried out strictly by the procedures mentioned in the ASTM standards. These tests include the Compressive Strength Test and the Modulus of Rupture Test. A table is presented below showing different ASTM Standards for determining hardened properties of concrete.

Table 5

ASTM Standards for determining hardened Properties of concrete

Hardened Concrete	ASTM Standard
Workability (Slump) Test	ASTM (C-134)
Compressive Strength Test	ASTM (C-39)
Modulus of Rupture Test	ASTM (C-78)

4.4.3 Coarse aggregates

Particles having size of more than 19mm and less than 4.75mm were removed during this process. locally available Sargodha crushed stone is used for preparing all mixes properties of coarse aggregates table below.

Table 6

Test results of coarse aggregate

S.	Coarse aggregate properties	Crush
1	Sp. Gr.	2.65 kg dm^{-3}
2	Water Absorption (%)	0.90%
3	Bulk Density	
	1. Loose	1294 kg m^{-3}
	2. Compacted	1397 kg m^{-3}
4	Fineness modulus	6.76 kg m^{-3}

Table 7

Mix designed test results Fine aggregate

Sr. No.	Fine Aggregate properties	M-1	M,2	M-3	M-4	M-5
1	Fineness modulus	2.15	1.12	1.88	2.63	2.88
2	Water absorption	1.19	1.73	1.76	1.79	1.65
3	Specific gravity	2.67	2.55	2.57	2.55	2.66
4	Silt content	0.10%	6.5%	5.00%	4.1 %	2.01%
5	Bulk Density					
	1. Loose	1430	1310	1335	1388	1434
	2. Compacted	1610	1470	1480	1505	1630

Table 8

Test result of slump

S.	Mix types	0.40 w/c ratio	0.45 w/c ratio	0.50 w/c ratio
1	M-1	76.2	76.22	77.35
2	M-2	38.1	45.4	50.8
3	M-3	44.4	43.6	52.4
4	M-4	50.8	55.83	60.3
5	M-5	42.1	45.3	54.6

Table 9

Test results of M30 design mixes

S.	Mix Types	Compressive strength at 28 days (N/mm^2)		
		0.40 w/c ratio	0.45 w/c ratio	0.50 w/c ratio
1	M-1	35.98	34.47	32.61
2	M-2	26.57	25.17	23.14
3	M-3	28.08	27.75	26.85
4	M-4	30.91	30.01	28.26
5	M-5	34.92	33.41	32.00

Table 10

Test results of M30 Design mixes

Sr. no.	Mix Types	Modulus of Rupture at 28 days curing (N/mm^2)		
		0.40 w/c ratio	0.45 w/c ratio	0.50 w/c ratio
1	M-1	5.18	4.98	4.80
2	M-2	4.58	4.03	3.90
3	M-3	4.88	4.25	3.98
4	M-4	5.15	4.62	4.20
5	M-5	5.55	4.81	4.90

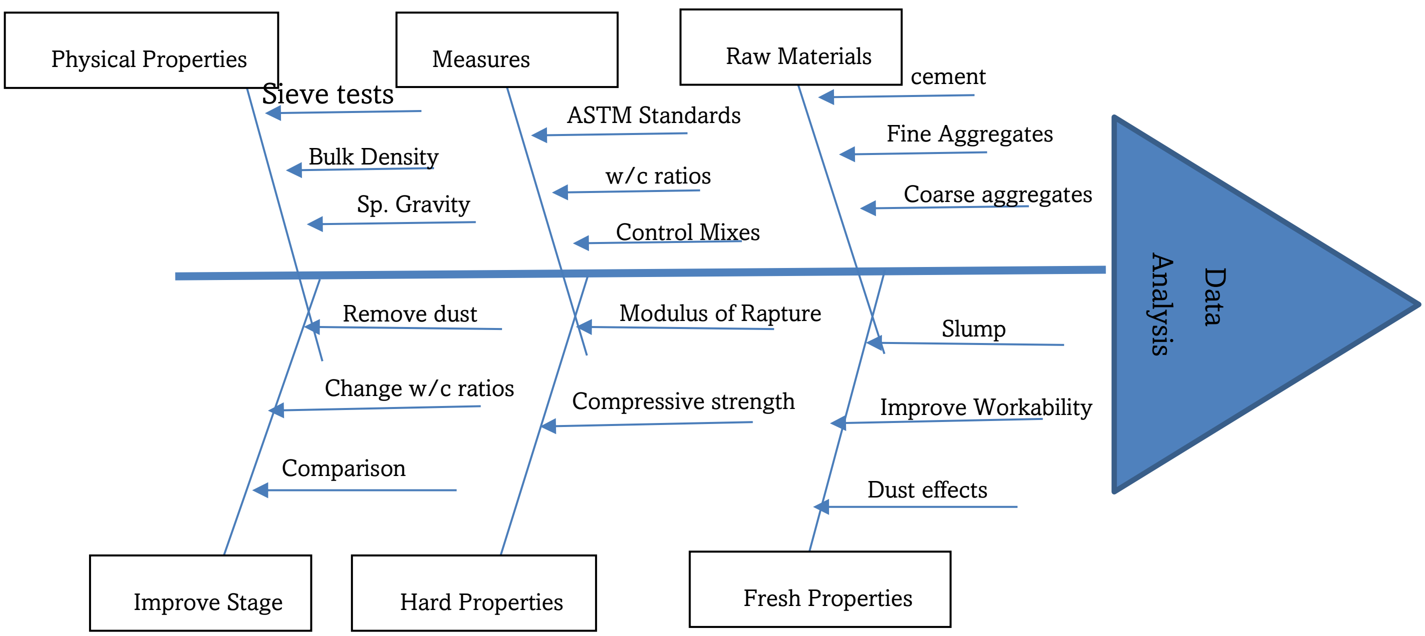

Fig. 3. Fish bone diagram data analysis

5. Discussions

They analyze and interpret the findings derived from conducting various tests on concrete samples, with the aim of addressing the research objectives. These findings have been presented in both tabular and graphical formats to enhance clarity and comprehension. Specifically, for the concrete grade of 30MPa, tests were conducted using locally available sands, namely Lawrencpur sand and Jhelum River sand. The objective was to investigate the impact of modifying the fine aggregate by incorporating crushed Sargodha coarse aggregate. The Lawrencpur sand mixtures were utilized as the control mix for comparative purposes. On the other hand, the Jhelum River sand mixtures were subjected to modifications by adjusting the fine aggregate gradation using crushed sand. During the experimentation, it was observed that the fineness of Jhelum River sand was found to be 1.12 less than the required range of 2.3-3.0. However, significant improvements in the fineness were achieved when the Jhelum River sand was partially replaced with crushed sand in the proportions of 30%, 40%, and 50% in the control mix. This indicates that the addition of crushed sand positively affected the fine aggregate gradation and brought it within the desired range.

Additionally, the study investigated the impact of partially replacing the fine aggregate with crushed sand, comparing it to the Lawrencpur sand control mix. The past study had not used six sigma as a enhance fine material to concrete strength. This analysis aimed to evaluate the influence of crushed sand on various concrete properties, such as compressive strength and flexural strength. By conducting a detailed comparison and analysis of the obtained results, it is possible to establish the significance of the current study and its contributions to the existing body of knowledge.

5.1 5 Concrete Properties in Fresh State

These properties of concrete i.e., workability was determined by performing a slump test on the mix, before casting or pouring concrete into the mold.

5.1.1 Slump test

A slump test was performed on fresh concrete samples to characterize their workability for all mix proportions. Each mix was cast in two batches and for each batch; slump was determined, and their average values are presented in tabular form in Table 8. A general trend from the above table.8 shows that slump value increases by modifying the fine aggregate gradation or enhancing the Fineness Modulus of the fine aggregate because aggregate becomes coarser and has better aggregate-aggregate packing due to fully graded aggregate gradation.

5.2 Hardened Concrete Properties

Following hardened properties of concrete were determined for each mix and their comparison with the reference Lawrencpur mix was made and is presented in both tabular and graphical form.

1. Compressive Strength

2. Modulus of Rupture

5.2.1 Strength of concrete in compression

The test to determine the compressive strength of concrete cylinders was performed in accordance with the specified procedure mentioned in ASTM C39 / C39M. The molded cylinders were kept under axial load in compression with a rate prescribed in the standard. The compressive stress/strength of sample can be calculated if the maximum applied load on specimen during the test is divided by x-sectional area of the specimen. Tests for computing Compressive stress/strength had been carried out on 28th days of casting. Compressive Strength Test Results are given above in Table 9 and their comparison in the form of bar chart is represented in Fig 4. A general trend observed from above bar charts shows that compressive strength increases when grading of fine aggregates becomes coarser or when fineness modulus of sand is enhanced by replacing its some percentage with crushed sand. Replacing some percentage of Jhelum River Sand with crushed sand makes coarser and leads to uniform or full particle size distribution satisfying the ASTM standard provided maximum and minimum grading limits for fine aggregates.

5.2.2 Modulus of rupture

Tensile load was applied to a concrete prism to determine the flexural strength of the samples. For this purpose, ASTM C78 / C78M was used. The flexural or tensile strength of a concrete sample is determined in this test by using a simple beam with two-point loading. Fig. 4.12 depicts the mechanism or assembly used for two-point loading. This test was carried out on three prisms on the 28th day of casting, and the results of the modulus of rupture test on prisms are shown in Table 10 and Fig. 3.MOR was increased.

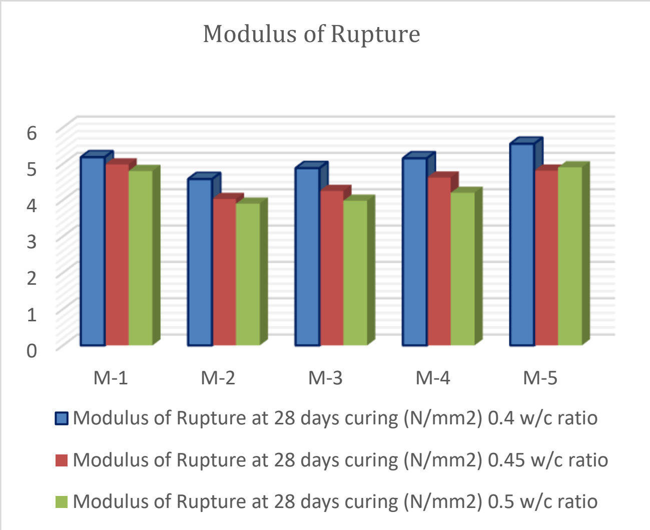

Fig. 4. Modulus of Rupture

Table 11

Defects in process material

S.	Defects Factor	M-1	M-2	M-3	M-4	M-5
1	Compaction	0	1	0	0	0
2	Sp. Gr.	0	1	1	0	0
3	Bulk Density	0	1	0	0	0
4	Fineness modulus	0	1	1	0	0
5	Water temperature	0	0	0	0	0
6	Water Absorption	0	1	0	0	0
7	Rate of loading	0	0	0	0	0
8	Silt	0	1	1	0	0

6. Improve Stage

The defects in the process and materials are recognized at this step of the DMAIC technique. Defects are detected during the manufacturing and processing of the concrete cube, followed by testing. The faults in the process and raw materials are shown in Table 11. There are 9 defects in the procedure.

7. Control Stage

7.1 Observer Final Response Variable

The final rejoinder capricious in this study is the compressive strength of M30 concrete after 28 days of curing. This step ensures that the reimbursements are sustained and that long-term problems are resolved. This stage is concerned with the design and analysis of the control system to sustain the quality level attained in the analysis of the study. Fig. 4 depicts a numerical analysis of the compressive strength of M30 concrete. The figure's limit is set to 30 N/mm2.

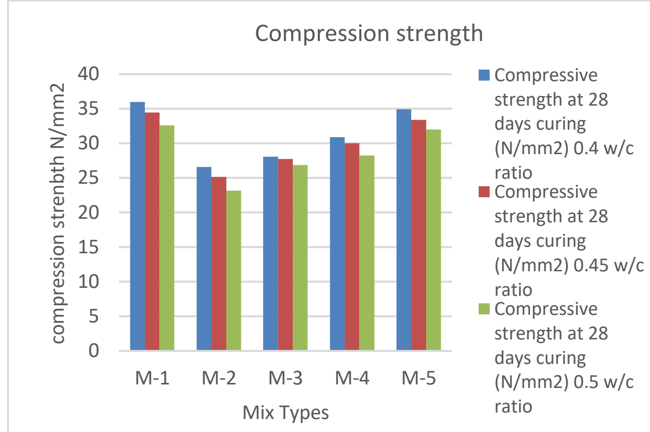

Fig. 5. Analysis of compressive strength of M30 Design concrete

8. Conclusion

During the examination of all five samples, a total of nine flaws were discovered. Seven of the nine flaws were in the material, and two were in the manufacturing process. Material defects can be easily avoided by using fine aggregate that has been treated to remove silt clay and replaced crushed sand. Process defects can also be avoided by conducting an expert investigation at the execution level. M30 concrete's compressive strength was calculated statistically.

- Workability determined through slump test shows that workability of Jhelum River Sand modified with crushed sand is in comparison to that of Lawrencpur sand (Control mix). Workability increases as the sand become coarser keeping the different w/c ratio because coarser are the aggregates particle lesser is the water required to make it workable.
- Compressive Strength increases up to 27% from the control mix of Lawrencpur sand when Jhelum River Sand is replaced with crushed sand up to 50%.
- Flexural Strength increases up to 20% in the case of Jhelum River sand replaced with crushed sand to Lawrencpur sand control mix.
- Cost analysis shows that modifying the locally available sands Jhelum River Sand with crushed stone sand gives a 7% to 10%
- Reduction in cost in comparison to Lawrencpur sand with better fresh and hardened concrete properties.

9. Recommendations

In the future, this research project can be extended to study the long-term effects on the concrete structure i.e., shrinkage cracking, by enhancing /improving the gradation of fine aggregate with crushed sand.

10. Acknowledgment

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Conflict of Interest

The authors declare that there is no conflict of interest.

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