Effect of Quartz Sand and Silica Fume on the Performance of High-Strength Concrete Under Elevated Temperatures

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Abstract: Concrete, as a widely used construction material, owes its remarkable properties to the careful selection and combination of various construction materials. Strength is a crucial characteristic of concrete, and the choice of construction materials greatly impacts its physical and mechanical properties. The purpose of this research is to determine the effect of properties of different construction materials and the mix design used with silica fume in the production of high-strength concrete and also to observe the effect of elevated temperatures on the strength of concrete. The results show that Quartz sand is the appropriate construction material for the production of high-strength concrete due to its excellent physical properties as compared to other fine aggregates. Similarly, the coarse aggregates in which locally available crushed stones, Sakhi Sarwar and Sargodha crush are used, and the results depicted that Sakhi Sarwar crush has a lower specific gravity, maximum water absorption, and higher abrasion value as compared to Sargodha Crush which leads to its negligible use in production of high strength concrete over Sargodha crush. In the next phase, different concrete mix designs are used to produce high-strength concrete by using silica fumes as a supplementary binding material. The maximum compressive strength has been achieved for the designed mix containing 15% silica fume and the addition of 0.2% Quartz sand in concrete. For the next phase of this research, the concrete mix with maximum compressive strength has also performed excellently under elevated temperatures up to 400^{o}C.

Keywords: Quartz Sand, Silica Fume, High Strength Concrete, Elevated Temperatures, Construction Materials

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1. Introduction:

Concrete is a compound which consists of any type of cement, fine aggregates, coarse aggregates and water with or without the addition of admixtures Ghaffar, et al., (2010). It is the most used construction material in the world because of its ease of molding and economy in civil engineering works. A thorough knowledge of concrete technology is, therefore, necessary for civil Engineering Khan, et al., (2023). We can say that the Ancient Romans were the first ones which use concrete in their constructions. Nowadays, there are two usually used construction and structural constituents which are highly in demand.

- Concrete
- Steel

In most cases, they both balance each other and maybe sometimes contest with one another, so that many structures of comparable manner and purpose can be manufactured using these two components. Still, most engineering universities & colleges teach much less about concrete than about steel. The man on the job needs to know more about the throughout behaviour of the concrete than about steel. Steel is always prepared in highly refined plants under careful precise circumstances and these characteristics of each type of steel are resolute in the laboratory and explained in the producer's certificate. Now the designer of any steel structure only needs to stipulate the steel fulfils a significant standard and now the construction needs only to confirm that accurate steel is used and the links among the members are wisely and accurately executed.

On any construction site, all the circumstances are changed. The Superiority of construction materials like cement is assured by the producer in a fashion similar to that by the producer of steel. In concrete, cement is not only a mandatory constituent, so concrete can be possible to achieve by a reedy-mix supplier but, even in this case, it is only the new constituents that are bought. As we are civil engineers, we know that carrying, insertion, and compaction significantly affect the final product at the concrete pouring site. Additionally, unlike the case of steel, the choice of concrete mixes cannot be made without knowing the characteristics of concrete and also the characteristics of its constituents, and the overall workability of concrete Ahmed, et al., (2023). Now it is the ability of the designer how govern the overall characteristics of concrete and also the ability of contrite actors and suppliers that regulate the authentic quality of the concrete mix in the completed structure. So, it is confirmed that they must be careful with all the characteristics and the overall behaviour of the concrete from carrying to insertion at the site.

1.1. High Strength Concrete (HSC)

According to ACI, HSC is concrete that has a compressive strength of almost 9000 psi or larger than 9000 psi Ghaffar, et al., (2010). And the concrete having compressive strength less than this value will be the concrete having normal strength. But we can’t take this as a deadline or separation line between these two types of concrete. In the recent few years, we have seen quick and huge progress in the awareness about HSC Gjørv, (2008). Also, we can say that much research has been dedicated to launching the essential characteristics of HSC structural members. We can say that the main drawback of HSC is its brittle performance. Production of HSC comprises the ideal usage of the main constituents that create concrete having normal strength Ahmad, et al., (2020). HSC is formed by improving the mix constituents, decreasing the w/c ratio, using a super plasticizer, and finally by changing the mineral admixtures like silica fumes, fly ash, etc (Sun, et al., 2020). By choosing a good quality cement, manufacturers improve the aggregates and hence improve the blend of constituents by changing the ratios of constituents. Larger span bridges can be made using High Strength Concrete Ali, et al., (2020).

1.2. Admixtures

In HSC, two types of mineral admixtures are frequently used namely silica fumes which have the most significance in HSC and other one is fly ash. These are the constituents that widely participate in achieving high strength by their reaction with Portland cement which produces C-S-H gel Wang, et al., (2011), which is highly accountable for gaining concrete strength Jindal, et al., (2020).

However, we can say that these admixtures greatly affect the strength and without the addition of these chemical admixtures, it will be difficult to gain high strength. We can use super plasticizers in High Strength Concrete because it increases the workability of concrete at low w/c proportions, hence giving high strength Kanamarlapudi, et al., (2020).

2. Literature Review:

Ghaffar, et al., (2010) found that after the curing of 14 days, the pores of concrete were filled because of pozzolanic activities and the porosity decreased after 28 – 56 days Ramezanianpour & Douglas, (2014). It was also found that the strength of concrete, made up of weak Margalla crush, starts reducing after 28 days.

Acker, (2004) found that the strain rate alters between 10-20 days due to the presence of C-S-H gel and after that, it swells. After 28 days, the High Strength Concrete achieves great strength up to an extent at which its swelling is impossible, increasing the internal stresses. It was also observed that the C-S-H gel is primarily subject to shear forces Manzano, et al., (2013).

Wang, et al., (2022) performed some with an observation period limited to 13 days, on lightweight aggregates. They found that there were little compressive forces in the first 3 days and after that, there was an increment of internal compressive forces up to 160 psi. these results were with lightweight aggregates.

Liu, et al., (2013) studied that the increase in the weight of concrete samples was due to the absorbed water by samples with the capillary action of the pores. He tells us that autogenously volume change can be massive and should be kept in mind while designing high-strength structures.

Liu, et al., (2013) recognized two different types of C-S-H gels.

- Low density
- High density

High-density gel is developed in a space limited by the already present low-density gel. It was found that initially low-density gel is formed in the ITZ Pan, et al., (2021). As densification develops the region among aggregate and low-density gel is filled with high-density gel applying compressive stresses on aggregate.

Jennings, et al., (2008) designated that for a crystal that is growing in a pore, it is the wall of the pore that applies stresses to stop the growth. The hydration process of cement results in a crystallization pressure of about 850 psi, which controls the capillary pressure.

Effect of Temperature on High-Strength Concrete

Behnood & Ziari, (2008) prepared High-Performance Concrete containing less w/c proportion and more contents of silica fumes which were 25% of the total binding material. The process of heating ranges between 200°C - 400°C after removing the samples from molds to increase the hydration reaction and pozzolanic reactions. This procedure upgrades the properties of High-Performance Concrete like mechanical properties and microstructural properties. The high compressive strengths of 200 MPa and 800 MPa can be achieved by the addition of steel fibres, which also enhances the concrete's elasticity.

Vejmelková, et al., (2012) performed experiments to determine the thermal properties of High-Performance Concrete like heat conductivity, heat diffusion, city, and continuous heat extension coefficient of High-Performance Concrete. The concrete used in French nuclear power plants were examined for temperature ranging between 20°C to 200°C, specific heat of -30°C to 100°C, precipitation diffusivity from 0 to 75% of ultimate water saturation at the room temperature, and water vapour diffusivity at the room temperature. The conclusion was correlated with the results of other producers for concretes with identical configurations showing fair compliance for most of the specifications.

Albéric, et al., (2018) explain the conclusions of samples cured with three different heating methods. The conclusions verified the production of Xonolite ($Ca_6 Si_6 O_{17} (OH)_2$) due to thermal application and the abstract tells that the kinetically controlled heat curing had a control on hydration and crystallization.

Wang, et al., (2015) examined the hydration and pozzolanic reaction by two High-

Performance Concrete samples with two alternate heating methods at 20º c and 250º c. The purpose of the experiment was to explore the effect of temperature on hydration and pozzolanic activity. At 250º c microstructural variations led to the existence of a Q3 peak that contributed to the production of Xonolite. The application of heat leads to a rise in the CS-H chain length due to the pozzolanic activity of silica fumes and quartz powder.

Jindal, et al., (2020) prepared a High-Performance Concrete by mixing crushed blast furnace slag, and silica fume with ordinary Portland cement. The ordinary Portland cement was altered with Fly ash and blast furnace slag at specified proportions. Quartz powder & basalt played an important role as an aggregate in the mixtures. 3 different curing processes:

- standard
- autoclave
- steam curing

These were implemented in the samples. The test conclusions show that High-Performance Concrete of compressive strength of more than 170 MPa is achieved by the mixing of a great number of mineral admixtures.

Shubbar, et al., (2019) explored a High-Performance Concrete at CSIR-SERC (Structural Engineering Research Centre), Chennai. It was found clear that the constituent's selection and curing methodology has a great role in the upgrade performance of High-Performance Concrete. We came to know that the high pozzolanic activity due to the addition of silica fumes enhanced the strength of High-Performance Concrete. A mix ratio has been developed by improving the volume of constituents, and curing methodology for the production of High-Performance Concrete of strength 193 MPa.

3. Methodology:

In phase 1, the tests on ordinary Portland cement were performed to determine its initial and final setting time. Then the fineness modulus test, and bulk density test in loose and compacted state on quartz sand, mountainous sand, Chenab sand, and on blend (mountainous and quartz sand) were performed. In the end specific gravity, water absorption, Aggregate impact value, and aggregate crushing value test on coarse aggregates were performed.

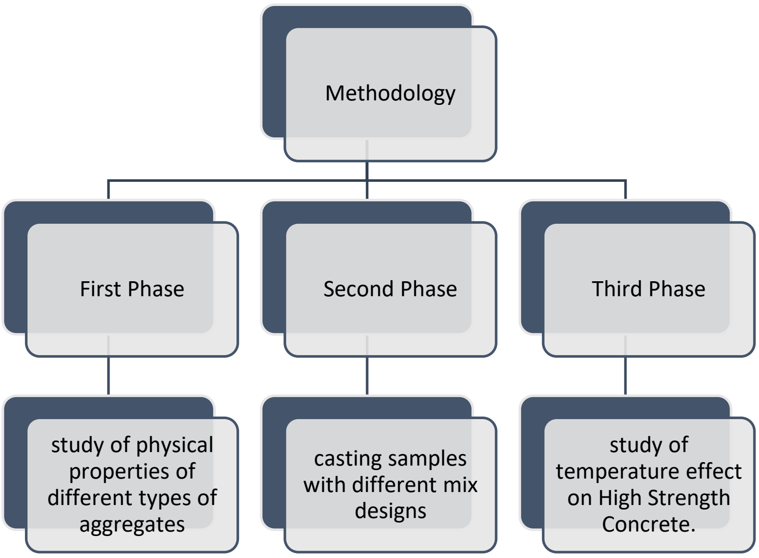


Figure 1: Flow Chart of The Methodology

4. Results:

Phase 1:

4.1.1. Tests Performed on Cement

Ordinary Portland cement of grade 43 is used. Following are the results of tests performed on cement:

4.1.1.1. Initial setting time of cement

The initial setting time of the ordinary Portland cement came out to 52 minutes. This result satisfies ASTM C150 – 04 which states that the initial setting time of ordinary Portland cement of grade 43 should be between 49 to 202 minutes.

4.1.1.2. Final setting time of cement

The final setting time of ordinary Portland cement came out to 298 minutes. This result satisfies ASTM C150 – 04 which states that the final setting time of ordinary Portland cement of grade 43 should be between 185 to 312 minutes.

4.1.2. Fine Aggregates

Four types of fine aggregates were used which are mountainous sand, Chenab sand, quartz sand, and the blend of mountainous and quartz sand. Following are the results of tests performed on fine aggregates:

4.1.2.1. Fineness Modulus Test

In table 1, column 1 shows no. of sieves, used to test the fineness modulus of Chenab sand. Column 2 shows the mass retained on each sieve respectively after shaking the set of these sieves in the sieve shaker for about 2 minutes. Column 3 shows the percentage of mass retained on each sieve and this is obtained by dividing column 2 by 100. Column 4 shows the cumulative percentage retained and this is obtained by taking the cumulative of column 3. Column 5 shows the cumulative percentage passing and this is obtained by subtracting column 4 from 100. Finally, the value of fineness modulus is obtained by taking the sum of the cumulative percentage retained which for Chenab sand is 241.6, and dividing it by 100. For Chenab sand value of fineness modulus came out to 2.41.

Table 1: Fineness modulus of Chenab Sand.

No of Sieve	Mass Retained	% Age Retained	Cumulative %age Retained	Cumulative %age Passing
# 4	20	2	2	98
# 8	32	3.2	5.2	94.8
# 16	70	7.0	12.2	87.8
# 30	342	34.2	46.4	53.6
# 50	318	31.8	78.2	21.8
# 100	194	19.4	97.6	2.4
∑	976	97.6	241.6	358.4

Fineness Modulus = 2.41

In table 2, column 1 shows no. of sieves, used to test the fineness modulus of quartz sand. Column 2 shows the mass retained on each sieve respectively after shaking the set of these sieves in the sieve shaker for about 2 minutes. Column 3 shows the percentage of mass retained on each sieve and this is obtained by dividing column 2 by 100. Column 4 shows the cumulative percentage retained and this is obtained by taking the cumulative of column 3. Column 5 shows the cumulative percentage passing and this is obtained by subtracting column 4 from 100. Finally, the value of fineness modulus is obtained by taking the sum of the cumulative percentage retained which for quartz sand is 295.4, and dividing it by 100. For quartz sand value of fineness modulus came out to 2.95.

Table 2: Fineness modulus of Quartz Sand

No of Sieve	Mass Retained	% Age Retained	Cumulative %age Retained	Cumulative %age Passing
# 4	0	0	0	100
# 8	0	0	0	100
# 16	4	0.4	0.4	99.6
# 30	959	96.3	96.3	3.7
# 50	27	2.7	99	1
# 100	7	0.7	99.7	0.3
∑	997	99.7	295.4	304.6

Fineness Modulus = 2.95

In Table 3, column 1 shows no. of sieves used to test the fineness modulus of mountainous sand. Column 2 shows the mass retained on each sieve respectively after shaking the set of these sieves in the sieve shaker for about 2 minutes. Column 3 shows the percentage of mass retained on each sieve and this is obtained by dividing column 2 by 100. Column 4 shows the cumulative percentage retained and this is obtained by taking the cumulative of column 3. Column 5 shows the cumulative percentage passing and this is obtained by subtracting column 4 from 100. Finally, the value of fineness modulus is obtained by taking the sum of the cumulative percentage retained which for mountainous sand is 250.6, and dividing it by 100. For the mountainous sand value of the fineness modulus came out to 2.50.

Table 3: Fineness modulus of mountainous sand

No of Sieve	Mass Retained	% Age Retained	Cumulative %age Retained	Cumulative %age Passing
# 4	0	0	0	100
# 8	2	0.2	0.2	99.8
# 16	300	30	30.2	69.8
# 30	192	19.2	49.4	50.6
# 50	224	22.4	71.8	28.2
# 100	272	27.2	99.0	1
∑	990	99.0	250.6	349.4

Fineness Modulus = 2.50

In Table 4 column 1 shows no. of sieves used to test the fineness modulus of a blend of quartz and mountainous sand. Column 2 shows the mass retained on each sieve respectively after shaking the set of these sieves in the sieve shaker for about 2 minutes. Column 3thee shows the percentage of mass retained on each sieve and this is obtained by dividing column 2 by 100. Column the 4 shows cumulative percentage retained and this is obtained by taking the cumulative of column 3. Column 5 shows the cumulative percentage passing and this is obtained by subtracting column 4 from 100. Finally, the value of fineness modulus is obtained by taking the sum of the cumulative percentage retained which for a blend of quartz and mountainous sand is 278.6, and dividing it by 100. For a blend of quartz and mountainous sand value of fineness modulus came out to 2.78.

Table 1: Fineness modulus of a blend (quartz sand and mountainous sand)

No of Sieve	Mass Retained	%Age Retained	Cumulative %age Retained	Cumulative %age Passing
# 4	18	1.8	1.8	98.2
# 8	26	2.6	4.4	95.6
# 16	56	5.6	10	90
# 30	490	49	59	41
# 50	52	5.2	64.2	35.8
# 100	354	35.4	99.6	0.4
∑	996	99.6	278.6	361

Fineness Modulus = 2.78

4.1.2.2. Comparison Fineness Modulus of Different Sand

Table 5 column 1 shows types of sand on which the test of fineness modulus was performed. Column 2 shows the fineness modulus of these sands that we obtained in Tables 4.1, 4.2, 4.3, and 4.4. Column 3 shows which type of sand these are. According to the standards of fineness modulus which were discussed in the previous chapter, if the fineness modulus is between 2.3 and 2.6 then it is fine sand, if the fineness modulus is between 2.6 and 2.9 then it is medium sand, and if it is in between 2.9 and 3.2 then the sand is coarse. So, Chenab and mountainous sand are fine sand blends of quartz, mountainous sand is medium sand and quartz sand is coarser sand.

Table 2: Fineness modulus of different sands

Type of Sand	Fineness Modulus	Conclusion
Chenab Sand	2.41	Fine Sand
Mountainous Sand	2.50	Fine Sand
BleA blend Quartz + mountainous Sand	2.78	Medium Sand
Quartz Sand	2.95	Coarser Sand

Figure 2 will help to explain the above-mentioned grading of fine, medium, and coarser sand. On the y-axis, the range of fineness modulus of the type of sand is plotted at the and on the x-axis. As you can see Chenab and mountainous are within the limit of fine sand, a blend of mountainous and quartz sand is within the limit of medium sand and quartz sand is within the limit of coarse sand.

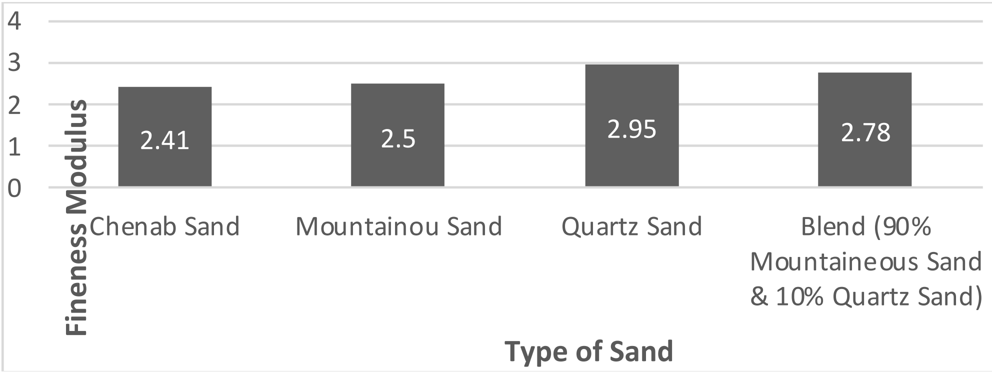


Figure 2: Comparison of fineness modulus of different sands

4.1.2.3.Loose Bulk Density

A bulk density test was performed on all four fine aggregates in a loose state and their results are given below:

Chenab Sand

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 3.820 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.35 kg/m^3

Mountainous Sand

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 3.912 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.40 kg/m^3

Blend (Mountainous Sand and Quartz Sand)

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 3.924 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.42 kg/m^3

Quartz sand

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 3.958 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.41 kg/m^3

Figure 3 shows the comparison between the bulk densities of mountainous sand, Chenab sand, quartz sand, and a blend of mountainous and quartz sand in a loose state. On the y-axis range of bulk densities is plotted in kg/m^3 and on the x-axis types of sand are plotted that we used for testing. Chenab sand has the lowest bulk density which is 1.35 which shows that concrete made from it will have a large no. of voids and it will be lightweight concrete. Mountainous sand and a blend of quartz and mountainous sand have a medium range of bulk density that is 1.40 and 1.42 which shows that it has a medium no of voids it will make medium-weight concrete and quartz sand has the highest bulk density that is 1.41 which shows that it has slightly less no of voids it will make slightly heavier concrete than the blend of quartz and mountainous sand.

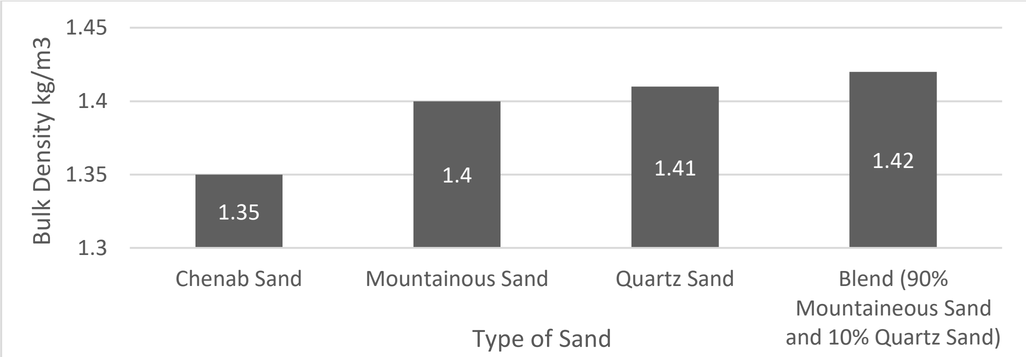


Figure 3: Comparison chart of loose bulk density of different sands

4.1.2.4.Bulk Density of Fine Aggregate in Compacted State

After performing the bulk density test on aggregates in a loose state, the bulk density test was performed in a compacted state:

Chenab Sand

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 4. 202 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.54 kg/m^3

Mountainous Sand

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 4.256 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.60 kg/m^3

Blend ((90% Mountainous Sand and 10% Quartz Sand)

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 4.331 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.61 kg/m^3

Quartz sand

Weight of mould = T = 1.170 kg

Weight of mould + Aggregate = G = 4.658 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.78 kg/m^3

Figure 4 shows the comparison between the bulk densities of mountainous sand, Chenab sand, quartz sand, and a blend of mountainous and quartz sand in a dense state. On the y-axis range of bulk densities is plotted in kg/m^3 and on the x-axis types of sand are plotted that we used for testing. Chenab sand has the lowest bulk density which is 1.54 which shows that concrete made from it will have a large no. of voids and it will be lightweight concrete. Mountainous sand and a blend of quartz and mountainous sand have a medium range of bulk density that is 1.60 and 1.61 which shows that it has a medium no of voids it will make medium-weight concrete and quartz sand has the highest bulk density that is 1.78 which shows that it has less no of voids it will make slightly heavier concrete than the blend of quartz and mountainous sand. Bulk densities of fine aggregates in dense states are larger than bulk densities in loose states which shows that in compacted states fine aggregates have lesser voids than in loose states.

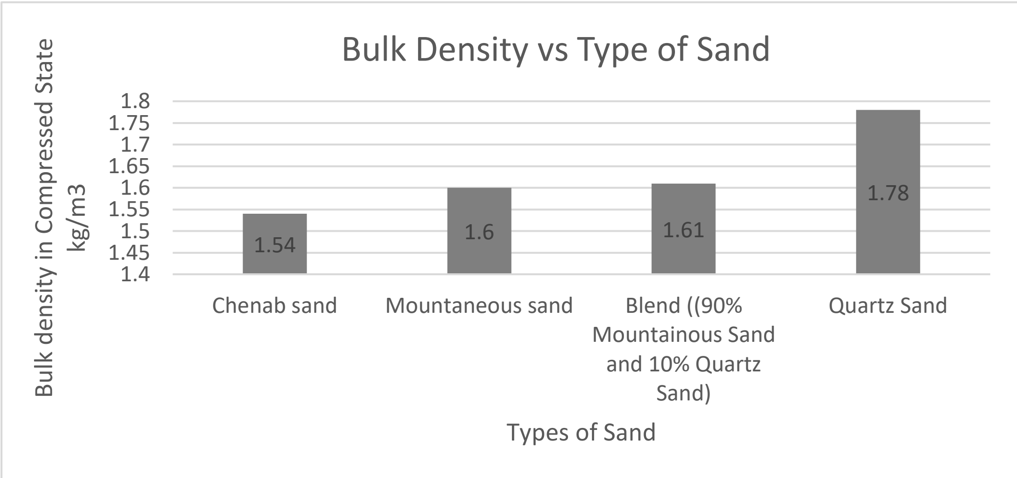


Figure 4: A comparison chart of compacted bulk density of different sands

4.1.2.5. Comparison of different fine Aggregate properties

As discussed before, the fineness modulus of mountainous sand and a blend of mountainous and quartz sand is between the finer and coarser sand. Finer and coarser sand will not be best suited for the sampling of high-strength concrete. The bulk density of mountainous and blend of mountainous and quartz sand in both compacted and loose states is in between the highest and lowest value which shows that the concrete made from these aggregates will neither be weighted nor heavy weighted. Considering all these factors we selected mountainous sand and a blend of mountainous and quartz sand for the sampling of High Strength Concrete.

4.1.3. Coarse Aggregates

Sargodha crush and Sakhi Sarwar crush were used for testing. Tests performed on Sargodha Crush and Sakhi Sarwar were specific gravity tests, water absorption tests, bulk density tests in a loose and compacted state, aggregate impact value, and aggregate crushing value. The results of these tests are given below

*4.1.3.1.*Specific Gravity of Coarse Aggregate

Sakhi Sarwar Crush

Weight of aggregate = A = 1000 gm

Weight of aggregate after 24 hours = B = 1036 gm

Weight of water in bucket = C = 589 gm

Specific gravity $= \frac{A}{B-C} = 2.24$

Sargodha Crush

Weight of aggregate = A = 1000 gm

Weight of aggregate after 24 hours = B = 1024 gm

Weight of water in bucket = C = 590 gm

Specific gravity $= \frac{A}{B-C} = 2.30$

Figure 5 shows the comparison of the results of specific gravity tests performed on the Sakhi Sarwar crush and Sargodha crush. On the y-axis range of specific gravity is plotted and on the x-axis types of crushes used for testing are plotted. As shown in the fig. value of specific gravity for the Sakhi Sarwar crush is 2.24 which indicates that the strength of the Sakhi Sarwar crush is less and its quality is poor while the specific gravity of the Sargodha crush is more which indicates that the strength of Sargodha crush is more and its quality is good.

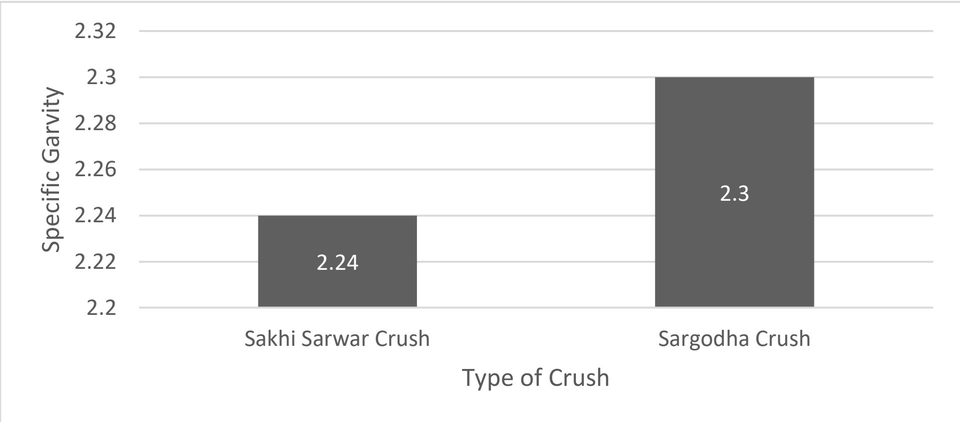


Figure 5: A comparison chart of the specific gravity of different crushes

*4.1.3.2.*Water Absorption of Coarse Aggregates

Sakhi Sarwar Crush

Weight of aggregate = A = 1000 gm

Weight of aggregate after 24 hours = B = 1036 gm

Weight of water in bucket = C = 589 gm

Water Absorption, % $= \frac{B-A}{A} \times 100 = 3.6$ %

Sargodha Crush

Weight of aggregate = A = 1000 gm

Weight of aggregate after 24 hours = B = 1024 gm

Weight of water in bucket = C = 590 gm

Water Absorption, % $= \frac{B-A}{A} \times 100 = 2.4$ %

Figure 6 shows the comparison of results of the water absorption test performed on the Sakhi Sarwar crush and Sargodha crush. On the y-axis range of water absorption is plotted and on the x-axis types of crushes used for testing are plotted. As shown in Figure 6, the value of water absorption for sakhi sarwar crush is 3.6% which indicates that the strength of sakhi sarwar crush is less as it can absorb more water because it is very porous while the value of water absorption for Sargodha crush is more which indicates that the strength of Sargodha crush is more as it can absorb less water because it is less porous.

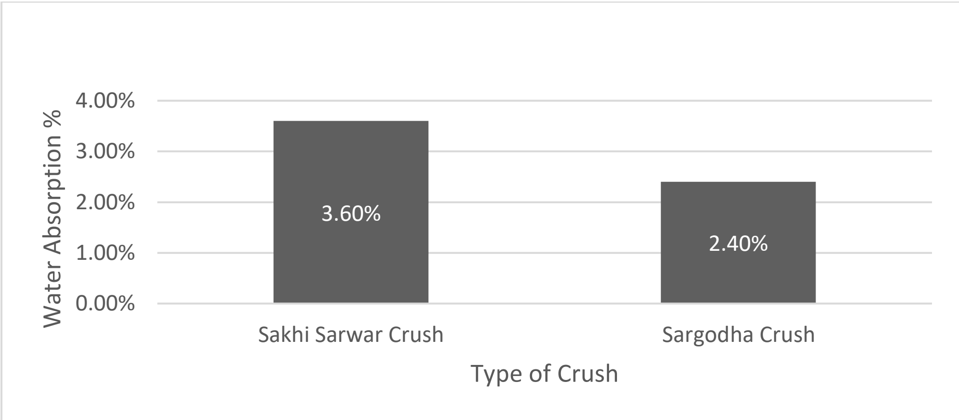


Figure 6: Comparison Chart of Water Absorption of Different Crusher

4.1.3.3.Bulk Density of Coarse Aggregates in Loosened State

Sakhi Sarwar Crush

Weight of mould = T = 1.15 kg

Weight of mould + Aggregate = G = 3.826 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.31 kg/m^3

Sargodha Crush

Weight of mould = T = 1.15 kg

other hand, Sargodha crush has a greater bulk density which is 1.37 which means types of crushes are plotted that we used for

Weight of mould + Aggregate = G = 3.724 kg

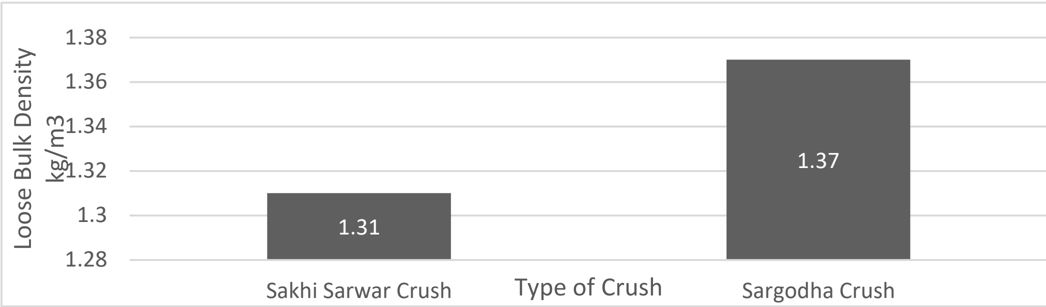
Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.37 kg/m^3

Figure 7 shows the comparison between the bulk densities of the Sakhi Sarwar crush and Sargodha crush in loose state e. On the y-axis range of bulk, densities are plotted in $kg/m^{3,}$ and on the x-axis concrete made from it will have a large no. of voids. On the

testing. Sarwari Sarwar crush has a low bulk density that is 1.31 which shows that aggregates are packed and the voids will be less in concrete made from it.

Figure 7: A comparison chart of loose bulk density of different crushes



4.1.3.4.Bulk Density of Coarse Aggregate in Compacted State

Sakhi Sarwar Crush

Weight of mould = T = 1.15 kg

Weight of mould + Aggregate = G = 3.928 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.41 kg/m^3

Sargodha Crush

Weight of mould = T = 1.15 kg

Weight of mould + Aggregate = G = 4.022 kg

Volume of Cylinder = 0.001959 m^3

Bulk Density = M = $\frac{G-T}{V}$ = 1.47 kg/m^3

Figure 8 shows the comparison between the bulk densities of the Sakhi Sarwar crush and Sargodha crush in a dense state. On the y-axis range of bulk densities is plotted in kg/m^3 and on the x-axis types of crush are plotted that we used for testing. Sakhi Sarwar Crush has a low bulk density that is 1.41 which shows that concrete made from it will have a large no. of voids. On the other hand, Sargodha crush has a greater bulk density which is 1.47 which means aggregates are packed and the voids will be less in concrete made from it.

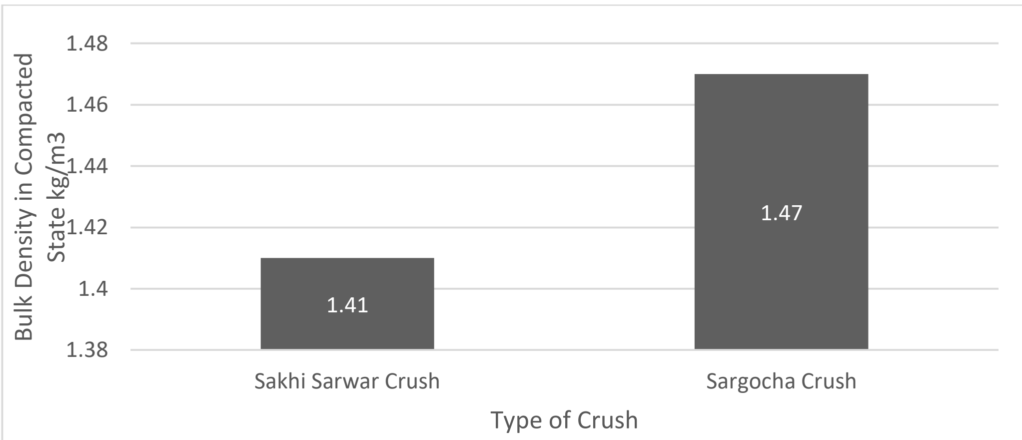


Figure 8: A comparison chart of compressed bulk density of different crushes

4.1.3.5.Aggregate Impact Value (AIV)

Sakhi Sarwar Crush

Weight of Mould = 1.886 kg

Weight of mould + Aggregate = 2.446 kg

Weight of Aggregate = A = 2.446 – 1.886 = 0.58 kg

Weight of Aggregate after 15 blows passing through Sieve # 8 = B = 0.074 kg

Aggregate Impact Value $= \frac{B}{A} \times 100 = \frac{0.074}{0.58} \times 100 = 12.75$ %

Sargodha Crush

Weight of Mould = 1.886 kg

Weight of mould + Aggregate = 2.442 kg

Weight of Aggregate = A = 2.442 – 1.886 = 0.556 kg

Weight of Aggregate after 15 blows passing through Sieve # 8 = B = 0.066 kg

Aggregate Impact Value $= \frac{B}{A} \times 100 = \frac{0.066}{0.556} \times 100 = 11.87$ %

Figure 9 shows the comparison between the aggregate impact value of the Sakhi Sarwar crush and the Sargodha crush. On the y-axis range of aggregate impact value is plotted in % and on the x-axis types of crush are plotted that we used for testing. Sakhi Sarwar Crush has a large percentage of aggregate impact value that is 12.75 which shows that aggregate has less resistance to sudden shock or impact and concrete made from it will have less strength. On the other hand, Sargodha crush has less percentage of aggregate impact value which is 11.87 which means aggregates have greater resistance to sudden shock or impact and the concrete made from it will have greater strength.

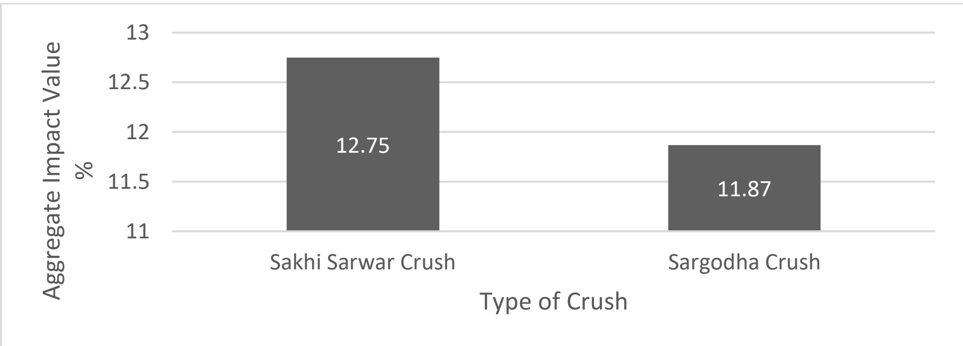


Figure 9: A comparison chart of aggregate impact value

4.1.3.6.Aggregate Crushing Value (ACV)

Sakhi Sarwar Crush

Weight of Mould = 1.170 kg

Weight of mould + Aggregate = 3.52 kg

Weight of Aggregate = A = 3.52 – 1.170 = 2.35 kg

Weight of Aggregate after 400 KN load has been applied for 10 minutes through Sieve # 8 = B = 0.378 kg

Aggregate Impact Value $= \frac{B}{A} \times 100 = \frac{0.378}{2.35} \times 100 = 16.08$ %

Sargodha Crush

Weight of Mould = 1.170 kg

Weight of mould + Aggregate = 3.448 kg

Weight of Aggregate = A = 3.448 – 1.170 = 2.278 kg

Weight of Aggregate after 400 KN load has been applied for 10 minutes through Sieve # 8 = B = 0.308 kg

Aggregate Impact Value $= \frac{B}{A} \times 100 = \frac{0.066}{0.556} \times 100 = 13.52$ %

Figure 10 shows the comparison between the aggregate crushing value of the Sakhi Sarwar crush and the Sargodha crush. On the y-axis range of aggregate crushing value is plotted in % and on the x-axis types of crush are plotted that we used for testing. Sakhi Sarwar Crush has a large percentage of aggregate crushing value that is 16.08 which shows that aggregate has less resistance to crushing under gradually applied compressive load and concrete made from it will have less strength. On the other hand, Sargodha crush has a lower percentage of aggregate crushing value which is 13.52 which means aggregates have greater resistance to crushing under gradually applied compressive load and the concrete made from it will have greater strength.

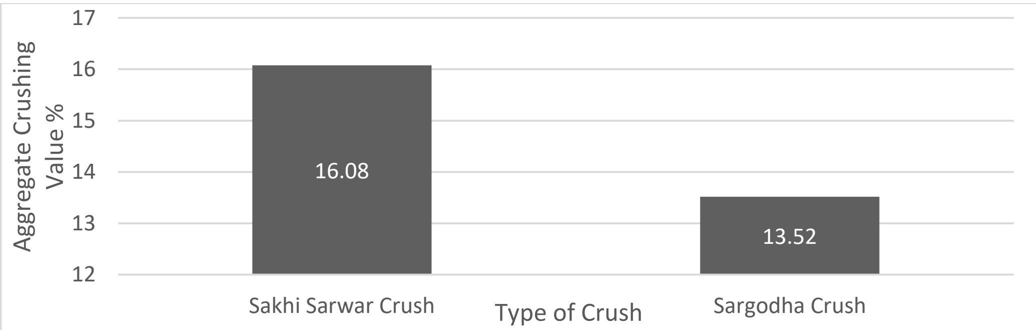


Figure 10: Comparison chart of aggregate crushing value

4.1.3.7.Comparison of different Coarser Aggregates properties

Table 4.6 compares Sakhi Sarwar Crush and Sargodha Crush. As the bulk density of Sargodha crush in both dense and compacted states is more than Sakhi Sarwar crush that means Sargodha crush has fewer voids which is good for the strength of concrete. The aggregate crushing value and aggregate impact value of the Sargodha crush is less than the Sakhi Sarwar crush which means that the Sargodha crush has more resistance against crushing and sudden shock. Water absorption of Sargodha crush is less than Sakhi Sarwar crush which means the Sargodha crush is less porous. The specific gravity of the Sargodha crush is greater than the Sakhi Sarwar crush which means the

Sargodha crush has more strength. Considering all the factors described above we selected Sargodha crush for sampling of High Strength Concrete.

Table 4: Comparison properties of different coarse aggregates

Sample	Bulk Density in Loose State kg/m^3	Bulk Density In Compacted State kg/m^3	Aggregate Crushing Value %	Aggregate Impact Value %	Water Absorption %	Specific Gravity
Sakhi Sarwar Crush	1.37	1.41	16.08	12.75	3.6	2.24
Sargodha Crush	1.31	1.47	13.52	11.87	2.4	2.30

Phase 2

In this phase, tests were performed on concrete samples. A compressive strength test on cubical concrete samples was performed. The trials were completed in 6 different sections. Each section has 6 trials. The results of which are given below:

Table 5 shows the first section of the trial. This section consists of 6 trials. In this section, we used cement, fine aggregates (mountainous sand), coarse aggregates (Sargodha crush), water in small amounts, and super plasticizers for sampling. We did not use silica fume in this section. In the trial, the no 1 ratio of cement used was 1.0, the ratio of fine aggregate was 1.5, the ratio of coarse aggregate was 2.0, the ratio of water was 30% of the binder (cement) and the ratio of super plasticizer was 3.0% of the binder. After 7 days of steam curing at a temperature of 80 degrees centigrade, the compressive strength of the first trial came out to 11.2 MPa. In trial, no 2 we decrease the ratio of fine aggregates from 1.5 to 0.80, and also, we decrease the water-cement ratio from 30% to 25%. As a result, our strength increased by 15%. In the trial, no 3 we further decrease the ratio of fine aggregate and w/c to 0.75 and 23% respectively. In this trial, we also decreased the ratio of coarse aggregate from 2.0 to 1.5 so, the strength of this trial increased by 72%. So, we randomly performed trials 4,5 by increasing or decreasing different ratios. In the end, we performed trial no 6 by considering the results of all the above trials. We used a ratio of 1:1:1.15, a w/c ratio of 20%, and a super plasticizer of 5% and our strength came out to 28.2 MPa.

Table 5: First section of the trial

S. No	Cement	Fine Aggregate	Coarse Aggregate	Silica Fumes %	W/C %	Super Plasticizer %	Strength after 7 days of Curing (MPa)
1	1.0	1.5	2.0	0	30	3.0	11.2
2	1.0	0.80	2.0	0	25	3.0	12.9
3	1.0	0.75	1.5	0	23	3.0	22.3
4	0.75	1.0	1.15	0	20	5.0	23.6
5	0.75	1.0	2.0	0	25	3.0	25.8
6	1.0	1.0	1.15	0	20	5.0	28.2

Table 6 shows the second section of the trial. In this section, we analyzed the effect of the ratio of silica fume on compressive strength. We kept constant the ratio of cement, fine aggregate, coarse aggregate, w/c, and superplasticizer as shown in the table. We did not use silica fume in trial no 1 then we used 2% silica fume in trial no 2 and kept on increasing the ratio of silica fume till our last trial of this section. It is clear from the table that with the increase of silica fume, the compressive strength of the concrete sample is increasing. The highest compressive strength achieved in this section was 39.7 MPa.

Table 6: Second section of trail

S. No	Cement	Fine Aggregate	Coarse Aggregate	Silica Fumes %	W/C %	Super Plasticizer %	Strength after 7 days of Curing (MPa)
1	1.0	0.75	1.5	0	23	3.0	22.3
2	1.0	0.75	1.5	2.0	23	3.0	28.0
3	1.0	0.75	1.5	4.0	23	3.0	33.8
4	1.0	0.75	1.5	6.0	23	3.0	32.0
5	1.0	0.75	1.5	8.0	23	3.0	36.5
6	1.0	0.75	1.5	10	23	3.0	39.7

Table 7 shows the third section of the trial. In this section, we analysed the effect of the ratio of silica fume on different mix designs. In this mix design, we used 0.75 ratios of cement, 1.0 ratio of mountainous sand, 1.15 ratio of Sargodha crush, 20% w/c ratio, and 5.0% super plasticizer and kept them constant in all trials of this section. We did not use silica fume in trial 1 and then we used silica fume 3% of cement and kept on increasing this percentage till the last trial as shown in the table. The compressive strength of concrete increases with the increase in the ratio of silica fume. Also, this section has greater compressive strength than the previous section which means that this mix design is better than the previous one. The highest compressive strength achieved in this section was 56.8 MPa.

Table 7: Third section of trail

S. No	Cement	Fine Aggregate	Coarse Aggregate	Silica Fumes %	W/C %	Super Plasticizer %	Strength after 7 days of Curing (MPa)
1	0.75	1.0	1.15	0	20	5.0	23.6
2	0.75	1.0	1.15	3.0	20	5.0	31.2
3	0.75	1.0	1.15	5.0	20	5.0	43.2
4	0.75	1.0	1.15	7.0	20	5.0	48.6
5	0.75	1.0	1.15	9.0	20	5.0	51.1
6	0.75	1.0	1.15	12.0	20	5.0	56.8

Table 8 shows the fourth section of the trial. In this section, we analysed the effect of the ratio of silica fume on different mix designs. In this mix design, we used 0.75 ratios of cement, 1.0 ratio of mountainous sand, 2.0 ratio of Sargodha crush, 25% w/c ratio, and 3.0% super plasticizer and kept them constant in all trials of this section. We did not use silica fume in trial 1 and then we used silica fume 2% of cement and kept on increasing this percentage till the last trial as shown in the table. The compressive strength of concrete increases with an increase in the ratio of silica fume. But this section has less compressive strength than the previous section which means that the previous mix design is better than this one. If we compare Tables 7 and 8 it is clear that with the increase of the ratio of coarse aggregate and w/c ratio and the decrease in the ratio of super plasticizer compressive strength of concrete decreases. The highest compressive strength achieved in this section was 50.2 MPa.

Table 8: Fourth section of trail

S. No	Cement	Fine Aggregate	Coarse Aggregate	Silica Fumes %	W/C %	Super Plasticizer %	Strength after 7 days of Curing (MPa)
1	0.75	1.0	2.0	0	25	3.0	25.8
2	0.75	1.0	2.0	2.0	25	3.0	33.9
3	0.75	1.0	2.0	4.0	25	3.0	40.1
4	0.75	1.0	2.0	6.0	25	3.0	36.5
5	0.75	1.0	2.0	8.0	25	3.0	43.6
6	0.75	1.0	2.0	10.0	25	3.0	50.2

Table 9 shows the fifth section of the trial. In this section, we use the same ratio of mountainous sand, Sargodha crush, w/c, and super plasticizer as in the third section of the trial. We just increase the ratio of cement in this section. We kept all these ratios till the last trial of this section. We did not use silica fumes in trial no 1 we used silica fume 3% of cement and we noticed with the increase of silica fume compressive strength of concrete increased we compare Tables 8 and 9 it is clear that by increasing the ratio of cement compression strength increases so, this mix design is better than the mix design used in the third section and is of the highest compressive strength which came out in this section was 65.3 MPa.

Table 9: Fifth section of trail

S. No	Cement	Fine Aggregate	Coarse Aggregate	Silica Fumes %	W/C %	Super Plasticizer %	Strength after 7 days of Curing (MPa)
1	1.0	1.0	1.15	0	20	5.0	28.2
2	1.0	1.0	1.15	3.0	20	5.0	39.8
3	1.0	1.0	1.15	6.0	20	5.0	51.2
4	1.0	1.0	1.15	9.0	20	5.0	53.1
5	1.0	1.0	1.15	12.0	20	5.0	59.2
6	1.0	1.0	1.15	15.0	20	5.0	65.3

Table 10 shows the sixth section of the trial. In this section, we used a blend of mountainous and quartz sand and we changed the proportion of mountainous and quartz sand in all trials with the change in the proportion of silica fume as shown in the table. We kept all the other ratios the same as in the previous section. As we know the compressive strength of High Strength Concrete after seven days of curing should be at least 70MPa. In the trial, no 6 in which the proportion of mountainous sand is 0.80% and quartz sand is 0.20% and the proportion of silica fumes is 15%, we achieved our required strength which is 78.1 MPa.

Table 10: Sixth section of trail

S. No	Cement	Fine Aggregate		Coarse Aggregate	Silica Fumes %	W/C %	Super Plasticizer %	Strength after 7 days of Curing (MPa)
		Sand	Quartz Sand					
1	1.0	1.0	0	1.15	0	20	5.0	65.3
2	1.0	0.95	0.05	1.15	3.0	20	5.0	65.8
3	1.0	0.90	0.10	1.15	6.0	20	5.0	68.2
4	1.0	0.885	0.115	1.15	9.0	20	5.0	69.3
5	1.0	0.85	0.15	1.15	12.0	20	5.0	75.6
6	1.0	0.80	0.20	1.15	15.0	20	5.0	76.2

Phase 3

In this phase, the effect of temperature on High Strength Concrete is studied. Table 11 shows that with the increase in temperature up to 400°C, the compressive strength of concrete rises. We selected the trial that gave maximum strength from the above mix designs provided in tables 6 to 10. So, we choose the 6th trial of Table 10. This trial gave us a strength of about 76.2 MPa. The ratio was 1:1:1.15. Silica fumes used were about 9% of cement. W/C was kept in 20% of the binder. The superplasticizer used in the concrete batch was about 5% of the binder (cement + Silica fumes).

Table 11: Study of the effect of temperature on trial 6 of Table 10

Temperature °C	Cube Strength after 7 days (MPa)	Cylinder Strength after 7 days (MPa)
25	76.2	62.4
100	80.6	63.1
200	87.8	63.8
300	85.3	68.6
400	90.2	71.7

Figures 11 and 12 show different compressive strengths at different temperatures. The graph shows that as the temperature rises, the compressive strength of the cube also rises.

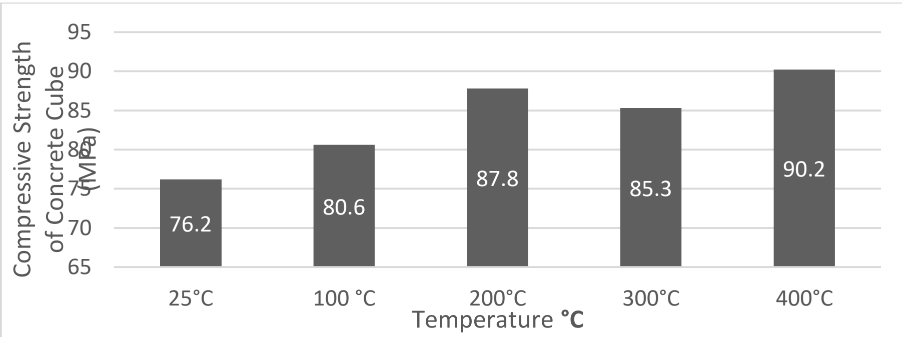


Figure 11: Compressive strength of concrete cubes at different temperatures

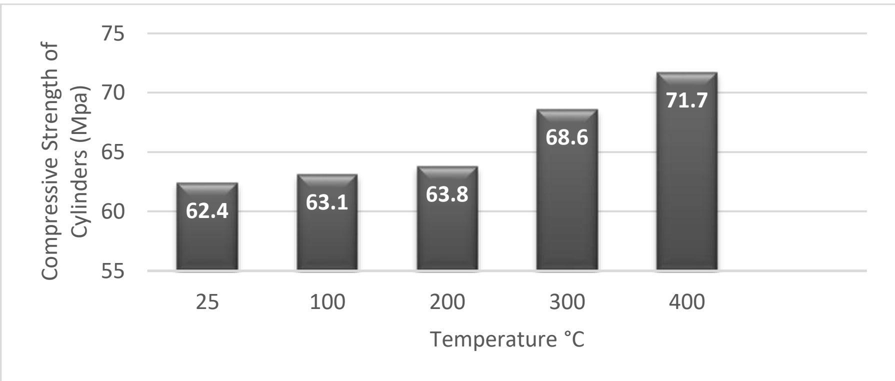


Figure 12: Compressive strength of cylinders at different temperatures

In this research, different types of materials were available. Different tests were performed on cement, fine aggregates, and coarse aggregates following conclusions:

- The initial setting time of the ordinary Portland cement came out to 52 minutes. This result satisfies ASTM C150 – 04 which states that the initial setting time of ordinary Portland cement of grade 43 should in between 49 to 202 minutes. The final setting time of ordinary Portland cement came out to 298 minutes. This result satisfies ASTM C150 – 04 which states that the final setting time of ordinary Portland cement of grade 43 should be between 185 to 312 minutes. If it does not specify the limit, this tells that the cement is not fresh or the cement is of poor quality.
- The fine aggregates available were mountainous sand, quartz sand, and Chenab sand. We performed tests on fine aggregates like fineness modulus and bulk density tests. We found that the blend of (90% mountainous sand and 10% quartz sand) has the best fineness modulus value and also gives the maximum strength when used in concrete.
- The coarse aggregates available were Sargodha Crush and Sakhi Sarwar Crush. Different tests were performed on coarse aggregates like Aggregate Crushing Value Test, Aggregate Impact Value Test, Bulk Density Test, Specific Gravity Test, and Water Absorption Test. We found that Sargodha Crush is the best one because it has greater Bulk Density and specific gravity, lesser water absorption, crushing value, use, and impact value.

5. Conclusions

In this research, about 90 samples were made and different batches of concrete were made. By changing the ratios of cement, fine aggregates, coarse aggregates, silica fumes, super plasticizer, and w/c ratio, the following conclusions were made,

- The water-to-water-cement ratio should not be greater than 30% of the binder. If it is greater than 30%, the workability of concrete also increases which affects the compressive strength of concrete.
- Super plasticizer which is used to improve the workability of concrete should not be greater than 5% of the binder. If we increase this percentage of super plasticizer, this will decrease the compressive strength of concrete.
- Silica fumes are used as a binder in concrete and it should not be greater than 15% of the amount of cement.

Increasing the amount will decrease the compressive strength.

- A blend of sands gives the best compressive strength results. The blend limits are as follows:
- For mountainous sand, the blend limit is 90% ≤ x ≤ 70% of the binder.
- For Quartz Sand, the blend limit is 10% ≤ x ≤ 30% of the binder.
- Coarse aggregates should be 1.15% of cement. As it gives the best compressive strength when used in concrete with this percentage.

To check the effect of temperature on concrete, about 24 samples were prepared. Out of 24 samples, 12 samples were cubes and 12 samples were cylinders. The following conclusion was made,

- The compressive strength of concrete increases when we place concrete samples, after curing for 7 days, in a furnace at a temperature range from 25°C to 400°C for 2 to 3 hours.

So, from the above conclusion, we can say that the greater the specific gravity greater the strength of aggregates, the greater the bulk density of fine aggregates, the better the compaction, and greater compressive strength will be achieved. If the fineness modulus is less, the finer will be the aggregate, hence water absorption will be more, and more heat of hydration will be produced. So, the aggregates will be considered to be poor or weak. Thus, an average value of the fineness modulus will give better results for compressive strength. Water to-cement ratio should be kept at less than 30%. To increase the workability of concrete, super plasticizers will be added. Silica fumes which will be used as a binder can increase compressive strength up to a certain limit but a greater ratio of silica fumes will decrease the compressive strength.

References:

Acker, P., (2004). Swelling, shrinkage, and creep: a mechanical approach to cement hydration. *Materials and Structures volume,* Volume 37, p. 237–243.

Ahmad, W., Farooq, S., Usman, M. & Khan, M., (2020). Effect of Coconut Fiber Length and Content on Properties of High Strength Concrete. *Materials*, 13(5).

Ahmed, A. et al., 2023). Analysis of Designs A Comparative Study of BIM and AutoCAD. *Southern Journal of Engineering & Technology.*

Albéric, M. et al.,(2018). The Crystallization of Amorphous Calcium Carbonate is Kinetically Governed by Ion Impurities and Water. *Advanced Science,* 5(5).

Ali, B., Kurda, R. & Herki, B.,(2020). Effect of Varying Steel Fiber Content on Strength and Permeability

Characteristics of High Strength Concrete with Micro Silica. *Materials,* 13(24).

Behnood, A. & Ziari, H., (2008). Effects of silica fume addition and water-to-cement ratio on the properties of high-strength concrete after exposure to high temperatures. *Cement and Concrete Composites,* 30(2), pp. 106-112.

Ghaffar, A., Siddiqi, A. & Ahmed, K. (2010). Assessing Suitability of Margalla Crush for Ultra High Strength. *Pak. J. Engg. & Appl. Sci.,* Volume 7, pp. 38-46.

Ghaffar, A., Siddiqi, A. & Ahmed, K. (2010). Assessing Suitability of Margalla Crush for Ultra High Strength Concrete. *Pakistan Journal of Engineering & Applied Science,* July, Volume 7, pp. 38 46.

Gjørv, O., (2008). High-Strength Concrete. In: *Developments in the Formulation and Reinforcement of Concrete.* s.l.:Woodhead Publishing Series in Civil and Structural Engineering, p. 153–170.

Jennings, H., Bullard, J., Thomas, J. & Scherer, G., (2008). Characterization and Modeling of Pores and Surfaces in Cement Paste. *Journal of Advanced Concrete Technology.*

Jindal, B., Jangra, P. & Garg, A., (2020). Effects of ultrafine slag as mineral admixture on the compressive strength, water absorption and permeability of rice husk ash based geopolymer concrete. *Materials Today: Proceedings,* Volume 32, pp. 871-877.

Kanamarlapudi, L., Jonalagadda, K., Jagarapu, D. & Eluru, A., (2020). Different mineral admixtures in concrete: a review. *SN Applied Sciences volume 2.*

Khan, A., Danish, M. & Ahmad, A., (2023). Utilization of Marble Powder, Bagasse Ash, and Wood Waste ash in Sustainable High-Performance Concrete. *Southern Journal of Engineering & Technology.*

Liu, R., Han, F. & Yan, P., (2013). Characteristics of two types of C-S-H gel in hardened complex binder pastes blended with slag. *Science China Technological Sciences,* Volume 56, p. 1395–1402.

Manzano, H., Masoero, E. & Lopez-Arbeloaa, I., 2013. Shear deformations in calcium silicate hydrates. *Soft Matter,* Volume 9, pp. 7333-7341.

Pan, J., Shen, Y. & Yang, G., (2021). Debonding behaviors and micro-mechanism of the interface transition zone in the sandstone-concrete interface in response to freeze-thaw conditions. *Cold Regions Science and Technology ,* Volume 191.

Ramezanianpour, A. & Douglas, R., (2014). A study on hydration, compressive strength, and porosity of Portland-limestone cement mixes containing SCMs. *Cement and Concrete*

Composites, pp. 1-13.

Shubbar, A., Al-Jumeily, D., Aljaaf, A. & Alyafei, M., (2019). Investigating the Mechanical and Durability Performance of Cement Mortar Incorporated Modified Fly Ash and Ground Granulated Blast Furnace Slag as Cement Replacement Materials. In: (*2019) 12th International Conference on Developments in eSystems Engineering (DeSE).* Kazan, Russia: IEEE.

Sun, J., Zhang, Z. & Hou, G., (2020). Utilization of fly ash microsphere powder as a mineral admixture of cement: Effects on early hydration and microstructure at different curing temperatures. *Powder Technology,* Volume 375, pp. 262-270.

Vejmelková, E., Keppert, M., Rovnaníková, P. & Ondráček, M., 2012. Properties of high-performance concrete containing fine-ground ceramics as supplementary cementitious material. *Cement and Concrete Composites,* January, 34(1), pp. 55-61.

Wang, D. et al., (2015). A review on ultra high-performance concrete: Part II. Hydration, microstructure, and properties. *Construction and Building Materials,* October, Volume 96, pp. 368-377.

Wang, L., He, Z. & Cai, X., (2011). Characterization of pozzolanic reaction and its effect on the C-S-H Gel in fly Ash-cement paste. *Journal of the Wuhan University of Technology-Mater. Sci. Ed.,* Volume 26, p. 319–324.

Wang, Y., Li, L., An, M. & Sun, Y., (2022). Factors Influencing the Capillary Water Absorption Characteristics of Concrete and Their Relationship to Pore Structure. *Applied Sciences Volume 12 Issue 4,* 12(4).