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Feasibility Study on Concrete Made with Substitution of Quarry Dust: A Review

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Abstract: Concrete mechanical properties could be improved through adding different materials at the mixing stage. Quarry dust (QD) is the waste produced by manufactured sand machines and comprise approximately 30–40% of the total quantity of QD generated. When it dries, it transforms into a fine dust that poses a tremendous hazard to the environment by contaminating the soil and water and seriously endangering human health. QD utilization in concrete is one of the best options. Though a lot of scholars focus on imitation of QD in concrete, knowledge is scattered, and a detailed review is required. This review collects the information regarding QD-based concrete, including fresh properties, strength, durability, and microstructure analysis. The results indicate that QD is suitable for concrete to a certain extent, but higher percentages adversely affect properties of concrete due to absence of fluidity. The review also indicates that up to 40–50% substitution of QD as a fine aggregate can be utilized in concrete with no harmful effects on strength and durability. Furthermore, although QD possesses cementitious properties and can be used as cement substitute to some extent, less research has explored this area.

Keywords: concrete; durability; quarry dust; slump; scan electronic microscopy

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1. Introduction

The word sustainable construction refers to management that creates a pleasant environment while taking ecological and resource development into account [1–5]. Concrete is quickly taking over as the primary construction material across the world due to its low cost and good performance as well as its availability [6,7]. However, the manufacture of cement has an influence on natural systems [8–11]. The production of cement, a vital component of concrete, is a significant cause of gas flows that are detrimental [12–14]. Each year, 3.6 billion metric tons of material are produced worldwide [15]. Cement production is anticipated to surpass 5 billion metric tons by 2030 [12,16]. Despite the fact that every country has its own set of conditions, part of the world's cement generates 11 billion metric tons of concrete each year, with the remainder being utilized for development [17]. To minimalize CO2 releases, concrete might be used alternative material in place of cement [18–22]. Besides cement, concrete also consumes billion of tons of natural sand and crushed stone which causes the depletion of natural resources.

In addition, the removal of river sand contributes to several issues, including water quality reduction, riverbank erosion, and riverbed damage, in addition to encroachment into river buffer zones [23,24]. To solve these issues, the building sector must adopt a sustainable strategy [25–27]. Different waste materials, such as marble waste [28], glass waste [29], copper slag [30], fly ash [31], and silica fume [32], have the capability to be utilized in concrete instead of cement or aggregates. In other words, the usual components of concrete may be replaced with alternative construction materials generated from industrial waste or recycled resources [12,33,34]. For the protection of natural assets, management of solid waste, enhancement of air excellence, and protection of the atmosphere, the construction sector must include sustainability [10,35]. Significant issues, including waste creation and the depletion of natural resources, have an impact on industrial productivity [12,36,37]. Over time, industrial waste builds up and seriously harms both the environment and people's health everywhere [11,38,39]. By identifying effective recycling solutions, the volume of garbage, related disposal costs, and environmental impact might be reduced [40–42]. The protection of natural resources and economic benefits are two further potential outcomes of such an effective plan [43]. Utilizing quarry waste as a potential substitute for fine aggregate and using the by-product of stone crushers is a way to achieve economic efficiency [44].

QD is a by-product of the aggregate crushing and production plants, as seen in Figure 1. QD improperly disposed of causes environmental issues, such as soil clogging, land degradation, water contamination, and air contamination [45]. QD, a substantial portion of the processed rock extracted from quarries serving the construction industry, is less suitable for use as cement because it lacks cementitious characteristics. Every year, a number of million cubic tons of quarry accumulate, the majority of which is made of dolomite or limestone. However, the incorporation of this waste material may lessen the impact such quarries have on the environment and lower the price of construction supplies by taking the place of a more costly raw material [46].

Figure 1. Quarry Dust [47].

QD may be used as aggregates for concrete, predominantly as natural sand. The rock is crinkled into dissimilar proportions during excavating operations. The dust produced during the process is stated as QD and it is created as waste and promotes air pollution. Therefore, QD would be utilized in construction developments to lower building expenses, protect building materials, and ensure the appropriate usage of environmental assets. Most growing countries are under stress to substitute partially or completely natural sand in concrete with another suitable substance without sacrificing the quality of the concrete. QD has been employed in the building business for different reasons, involving bricks, tiles, and aggregates for roads, in addition, to being a promising building material [48]. Figure 2 shows the application of QD. It can be noted that the maximum utilization of QD is in concrete products (46%). Although QD can be utilized in different types of concrete, such as lightweight concrete, self-compacted concrete, etc., the maximum utilization was reported in fiber-reinforced concrete.

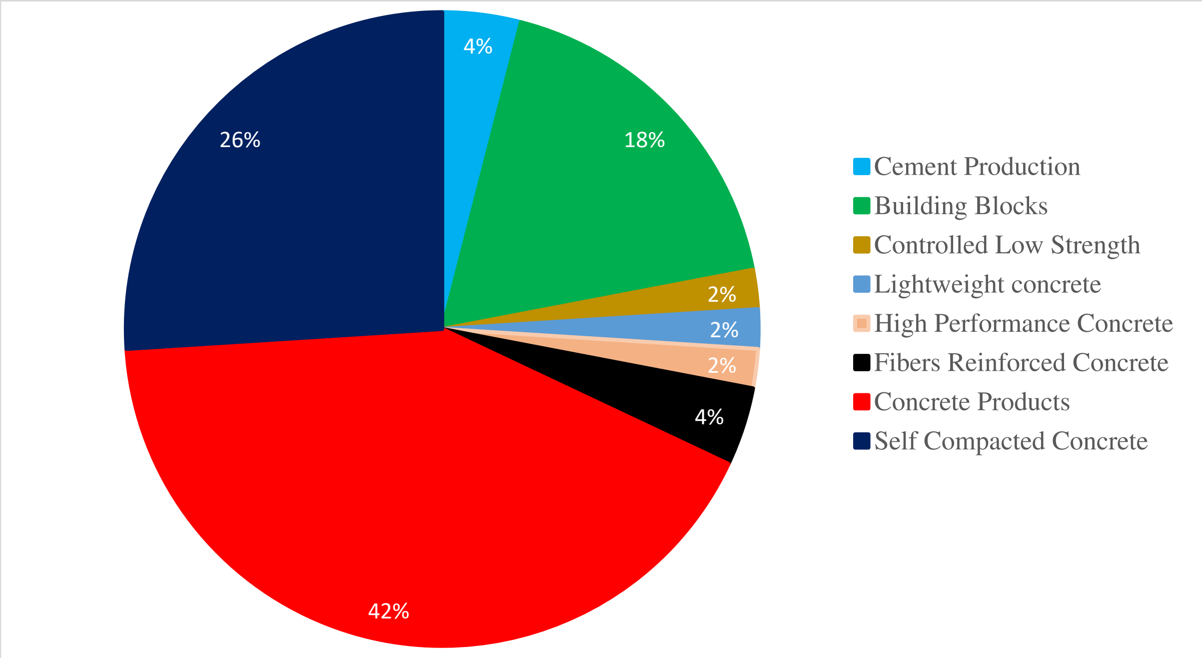

Figure 2. QD Utilization in Construction Materials [49].

QD powder's sticky nature makes it difficult to transport, which increases the requirement for it to be used on-site. Due to this criterion, QD powder may now be partly utilized in concrete, which is a useful use [50]. The findings and economic viability support the use of river sand in lieu of 20% of the total amount of granite fines when producing concrete [24]. Improvements in workability and tensile qualities were said to replace up to 60% of the QD in substations [51]. QD replacement of up to 60% of the original material was observed to increase compressive strength (CS). With QD, it was noted that the modulus of elasticity improved, the abrasion resistance increased by up to 30%, and the tensile strength (TS) increased by up to 15% [50]. According to research, the strength of concrete increased steadily when QD totally replaced fine aggregate in the concrete mix [52]. The capacity to use QD as a sand replacement material, as highlighted by Mir et al. [53], revealed that the strength characteristics and elastic modulus improved. By substituting QD in a 60:40 ratio for fine aggregates, the CS was increased. To guarantee sustainable growth in the building sector, concrete that uses QD as a fine aggregate and is made with high-quality components, a sufficient amount of superplasticizers in order to keep constant w/c ratio constant, efficient mixing techniques, and correct curing may be employed [54]. Research revealed in their work that they employed QD and lateral sand as a partial substitute for natural sand while making concrete. It was discovered that the flexural strength (FS) and tensile strength (TS) have increased as a consequence [55].

Although a lot of scholars focus on the imitation of QD in concrete, the information is scattered, which restricts its application, and detailed analysis is necessary. This review collects information already carried out in the research by other researchers on QD-based concrete. The important parameters of concrete, such as fresh properties, mechanical strength, durability aspects, and microstructure analysis, are taken the main aspects of this study. The results indicate that QD is suitable for concrete up to a certain extent due to micro filling and pozzolanic activity, but higher percentages adversely affect the strength and durability of concrete due to the absence of fluidity. The review also indicates that up to 40–50% QD as fine aggregate can be utilized in concrete with no harmful effect on the mechanical strength and durability of concrete.

2. Physical and Chemical Properties

The physical characteristics of QD used in concrete are shown in Table 1. Various researchers noted various physical characteristics of QD. These could be caused by a shift in the area or the QD's source. QD has a specific gravity of roughly 2.80, which is somewhat lower than that of cement (3.0). Overall, QD's physical characteristics indicate that it may be employed as an element in concrete.

Table 1. Physical Properties QD.

Reference	[56]	[57]	[58]	[50]	[20]
Specific gravity	2.75	2.83	2.50	1.74	2.60
Water Absorption (%)	2.91	1.50	0.50	2.34	1.3
Fineness Modulus	2.40	2.46	2.90	-	-
Moisture Content (%)	1.23	-	-	-	-
Bulk density (kg/m^3)	1730	1695	-	1550	1750

Scanning electron microscopy (SEM) pictures of cement and QD are shown in Figure 3. Cement has more uniform particles and a smooth surface (Figure 3a). Similar to limestone filer (LF) grains, these particles have an angular form and a rough surface and are present in substantial numbers at sizes of 10 m and lower (Figure 3b). Due to increased friction, QD's angular form reduced the flow characteristics of concrete. However, the interlocking of the angles may boost the strength characteristics of the concrete.

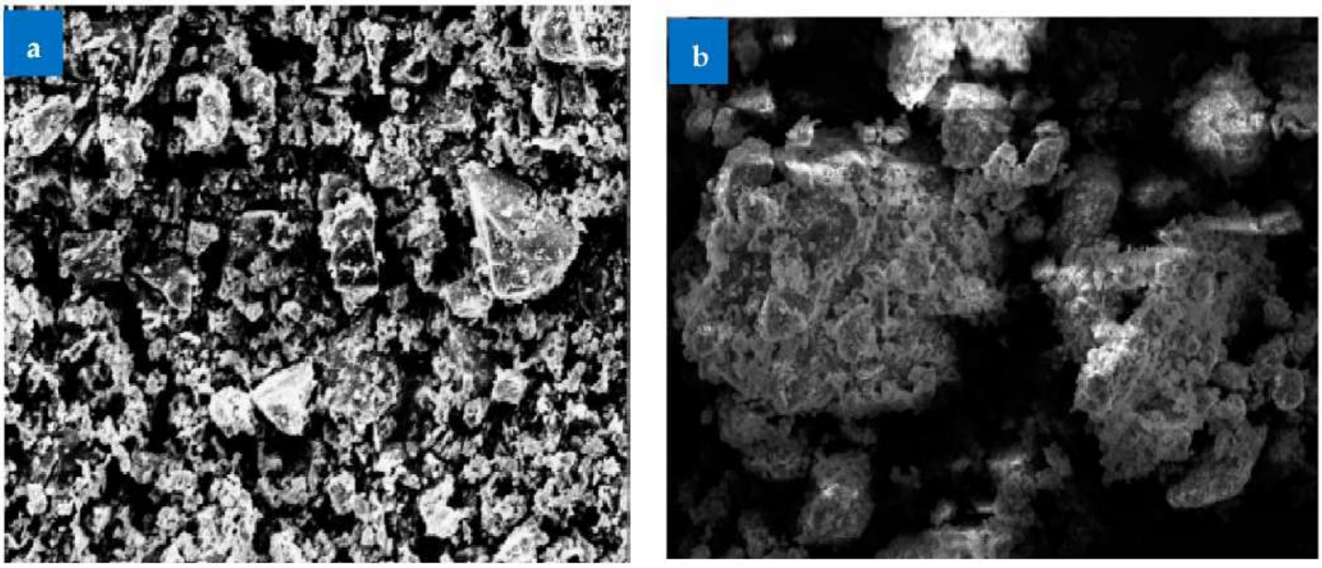

Figure 3. SEM of (**a**) Cement and (**b**) Quarry Waste [59].

The chemical composition of QD is displayed in Table 2, and its X-ray diffraction (XRD) is shown in Figure 4. QD contains more than 70% of the following elements combined: silica, iron, lime, magnesium, and alumina. QD has the ability to be employed as a binder replacement in concrete according to XRD and chemical analyses of the dust. The bulk of the natural sand, according to the study, was composed mostly of quartz, but the tailings also included other minerals [60].

Table 2. Chemical Composition of QD.

Reference	[61]	[62]	[46]	[63]	[64]
SiO_2	11.79	62.48	3.70	65.73	62.48
Al_2O_3	2.17	18.72	1.7	19.31	18.72
Fe_2O_3	0.68	6.54	0.96	1.39	6.54
MgO	1.80	2.56	18.30	1.47	2.56
CaO	45.7	4.83	74.8	2.79	4.83
Na_2O	1.72	-	0.07	1.63	-
K_2O	0.84	3.18	0.22	1.81	3.18

When cement is hydrated, calcium hydrates (CH), which are formed from the amorphous silica present in the QD process, develop, yielding additional cementitious chemicals, such as calcium silicate hydrate (CSH) gel. CSH possesses cementitious properties that improve the cement paste's ability to bind, improving the strength and stability of the concrete in the process. Additionally, research indicates that CSH fills any gaps left by a cement paste, strengthening and prolonging the life of concrete [65].

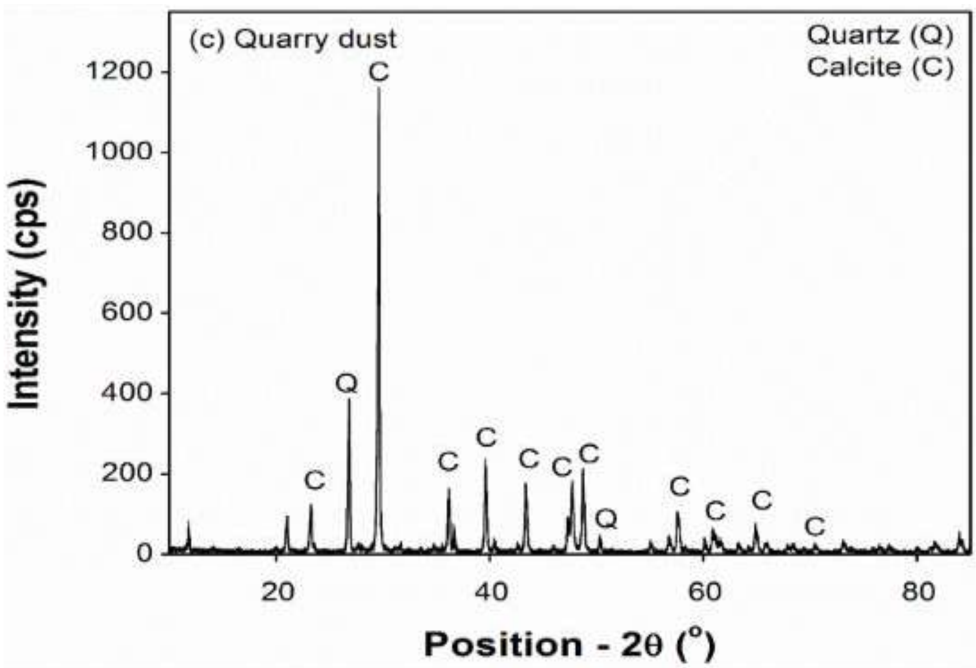

Figure 4. XRD Pattern Of QD [66].

3. Fresh Concrete

3.1. Setting Time

Figure 5 shows the initial setting time and final setting times of concrete. The initial and final setting times are extended with limestone. Similarly, studies also reported that secondary cementitious materials extend the setting of concrete due to the pozzolanic reaction [37,67]. The pozzolanic reaction proceeds slowly as compared to the hydration of cement.

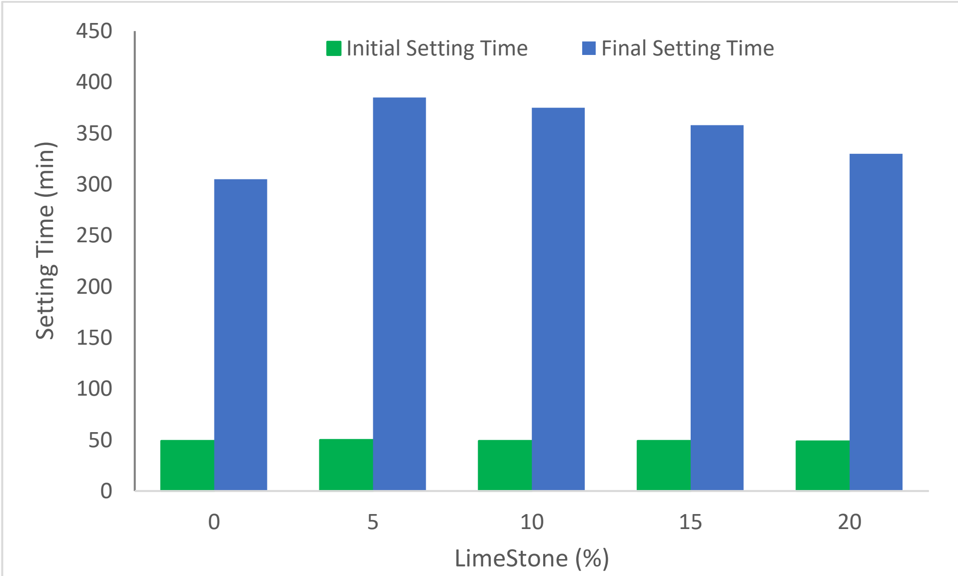

Figure 5. Setting Time [68].

When the limestone concentration rises by up to 20%, however, the initial and final setting times are slightly decreased. Since limestone offers nucleating sites for its development, it facilitates the early synthesis of calcium hydroxide. Additionally, with the inclusion of limestone, higher levels of ettringite are seen at early ages [69]. Limestone has certain physical impacts and chemical effects. The material fills the void between the clinker grains because of its fineness. It produces carbo aluminate when it combines chemically with the aluminate phase [70]. According to research, 20% limestone takes longer to set than 0%. This is due to the decreased pozzolanic reaction [68]. The hydration product of cement, calcium hydroxide ($Ca(OH)_2$), reacts with pozzolanic materials at the beginning of the process to promote hydration, increase the exothermic rate of cement hydration, shorten the time needed for the hydration induction period, advance the acceleration period, and shorten the deceleration period. With the inclusion of nano-silica, pastes' initial setting time and final setting time were reduced [71].

3.2. Slump Flow and Compaction Factor

Figure 6 shows the slump flow of concrete with partial substitution of QD. It can note that QD decreased the flowability of concrete due physical nature (rough surface and porous nature. Therefore, QD absorbs more water and hence less free water is available for lubrication. Moreover, the rough surface nature increased the friction between concrete ingredients which resists the flow of concrete. However, more cavities were formed, and a higher percentage of water absorption was attained at higher QD concentrations, which decreased the amount of water available for excellent workable concrete [56].

Research indicated that the standard concrete compatibility is 0.95. Workability is 0.94 for QD at 20%. For concrete that has had 30% of its original material changed, compatibility is further reduced to 0.93. Compatibility for 40% of QD concrete is 0.90, and for 50% alternative of QD concrete, a 0.89 compacting factor was noted [48]. Concrete containing QD has less flowability because it absorbs more water. Additionally, QD has a rougher surface texture than natural sand, which reduces the flow characteristics of concrete.

For several mixes, the calculated slump values of QD concrete were found to be in the range of 37–60 mm. It was discovered that the slump value rises when QD replaces more sand in the mix. Concrete does not provide appropriate workability and has a tendency to separate because of the flaky particle form and increased proportion of fines. The aforementioned slump value is indicative of a low degree of workability and is ideal for the production of tiles, bricks, canal lining, and autoclave blocks [72].

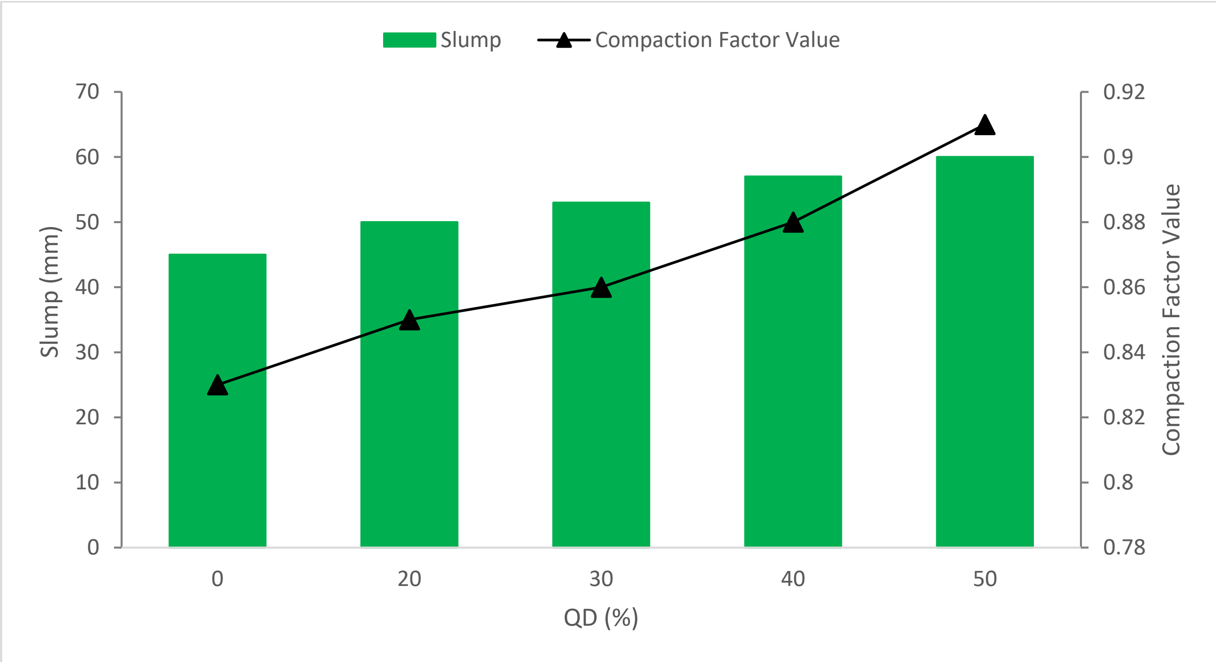

Figure 6. Slump Flow and Compaction Factor: Data Source [72].

As the concentration of QD increased, the slump shrank. More water was absorbed by QD particles than by sand, which had an adverse effect on the concrete mix's workability. For the concrete mix that substituted 40% QD for fine aggregates, the slump was kept to a minimum [64]. Utilizing both fly ash and QD simultaneously, a researcher looked at the qualities of a concrete mixture. They contrasted standard concrete with that made using QD as the river sand and fly ash instead of cement to varying degrees (10%, 15%, and 20% respectively). With more QD present, slump values drop. Fly ash is added, which lessens the effect of adding QD on the material's workability [73].

QD powder has lower workability as its specific surface area increases due to its finer nature, which causes water combined with concrete to absorb the particles and raise the specific surface area. The workability is significantly reduced at a replacement level of 60%, which results in less compaction and a rise in the amount of empty spaces in the mixture. This will explain the lower modulus of elasticity value at a replacement level of 60% [50]. Table 3 depicts the summary of the slump of concrete with QD substitution.

Table 3. Slump of Concrete with QD.

Reference	Quarry Dust	Water to Binder Ratio	Optimum	Slump (mm)	Remarks
[56]	0%, 10%, 20%, 30% and 40%	0.45	20%	88, 109, 110, 94 and 89	Increased
[74]	0%, 25%, 50%, 75% and 100%	0.47	-	85, 60, 65, 70 and 70	Decreased
[58]	0%, 20%, 25%, 30% and 35%	0.44	30%	45, 50, 52, 58 and 60	Increased
[72]	0%, 20%, 30%, 40% and 50%	0.55	30%	37, 45, 50, 54 and 60	Increased
[44]	0%, 20%, 30%, 40% and 50%	0.45	40%	M25 8, 9, 8, 8 and 7 M30 6, 9, 6, 6 and 6	No effect
[64]	0%, 10%, 20%, 30% and 40%	0.45	30%	60, 55, 35, 27 and 20	Decreased
[75]	0%, 15%, 35%, 55% and 75%	0.40	35%	95, 89, 78, 67 and 55	Decreased

4. Strength Properties

4.1. Compressive Strength (CS)

The replacement of QD boosted the concrete's CS to some extent, as seen in Figure 7 and Table 4. When compared to the matching reference concrete after seven and 28 days, mixes including QD powder had CS that was 60–80% and 30–40% higher, respectively [76]. According to research, concrete's CS is around 20% more than it is for regular concrete. Additionally, they claimed that the small pieces of powdered limestone acting as a filler in the spaces between the aggregates were responsible for the increase in the CS of self-compacting concrete (SCC) [77]. According to research, adding QD may boost CS by filling up vacancies in the concrete matrix [78]. The increased CS is due to the micro-filling effects of QD which fills the voids in concrete ingredients, leading to more dense concrete and hence more strength. Furthermore, due to the pozzolanic reaction QD, secondary cementitious compounds form such as calcium silicate hydrates (CSH) which improved the binding properties of cement paste. The combined micro filling and the pozzolanic reaction of QD have a positive influence on the strength. However, at a higher dose of QD, strength decreased due to a lack of flowability, which causes more voids in hardened concrete.

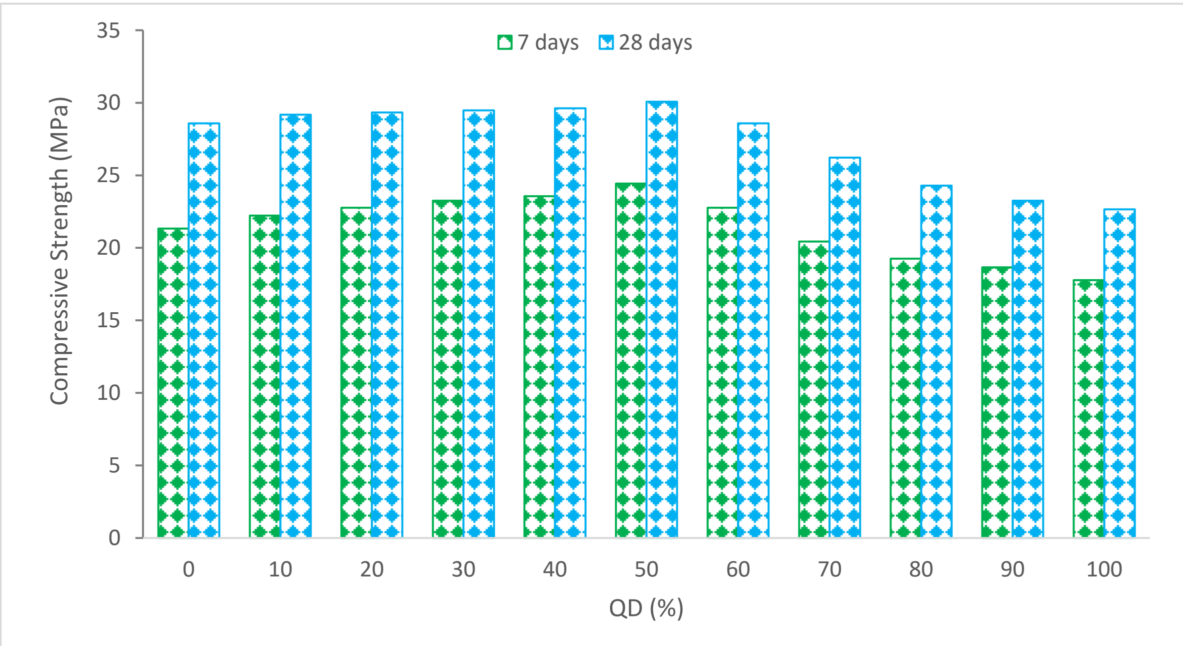

Figure 7. Compressive Strength: Data Source [79].

According to research, replacing sand with QD powder results in an increase in strength up to a point of 60%, after which there is a sharp decline in strength. This observed boost in strength may be due to the QD powder filling the spaces between the sand, creating a specimen that is denser and more bound (filler effect). Given that QD powder has a greater specific surface area due to its finer texture, water added to the mixture takes longer to absorb the particles, decreasing workability as QD powder content rises. Its poor workability during casting is blamed for the low CS found for combinations with 75% replacement [50]. The use of QD in lieu of sand while producing concrete was also investigated. Results indicated that when QD replaced sand by 50%, the CS increased to a high of 19.18% [79].

When fine aggregate is substituted with 50/50 marble sludge powder and quarry rock dust, the concrete mixture performs very well in terms of strength and quality. According to the findings, a blend of 50% QD produced greater CS and breaking TS. The CS and TS of concrete are affected but the workability is improved when the marble sludge powder content is increased by more than 50% [80].

When fine aggregates were replaced with QD to a maximum of 30%, CS increased; beyond that, it started to decline. The maximum CS evaluated at 28 days was 26% more than the control mix, which corresponds to the concrete mix using 30% QD in lieu of river sand. It was discovered that the CS of concrete with a 40% QD component was less than the control mix [64]. The results show that after seven and 28 days, the CS of the specimen mixed with 35% sand and 3% cement substituting the stone dust improves by 21.33% and 22.76%, respectively, compared to the standard mortar specimen [81]. The CS rises to 22% over the control mix with the addition of 15% fly ash and 15% QD. CS drops to 20% when QD and fly ash makes up 30% of the mixture. Thus, adding fly ash and QD at a rate of 15% produces the best results [82]. In contrast, the research found that quarry concrete's CS is somewhat lower than that of sand concrete because of the poorly graded particles in the QD and the extreme flakiness [73].

Table 4. Compressive Strength (CS) of Concrete with QD.

Reference	QD	Water to Binder Ratio	Optimum	Compression Strength (MPa)
[56]	0%, 10%, 20%, 30% and 40%	0.45	20%	7 Days 18, 22, 24, 19 and 18 28 Days 28, 34, 35, 30 and 28
[74]	0%, 25%, 50%, 75% and 100%	0.47	-	7 Days 35, 24, 30, 31, 32 and 33 28 Days 41, 30, 32, 39, 39 and 40
[57]	0%, 50% and 100%	0.53	50%	7 Days 31.06, 38.44 and 38.10 14 Days 33.17, 41.99 and 39.03 28 Days 44.24, 45.83 and 45.32
[58]	0%, 20%, 25%, 30% and 35%	0.44	30%	14 Days 31, 32, 33, 33 and 32 28 Days 36, 37, 39, 39 and 36
[72]	0%, 20%, 30%, 40% and 50%	0.55	30%	7 Days 23, 25, 27, 24 and 22 28 Days 30, 34, 31, 24 and 26 91 Days 37, 36, 37, 35 and 33
[50]	0%, 20%, 40%, 60% and 80%	0.56	60%	7 Days 7, 10, 17, 19 and 15 28 Days 10, 10, 20, 27 and 20
[48]	0%, 20%, 25% and 30%	0.45	30%	3 Days 18.9, 17.93, 17.85 and 20.74 7 Days 28.44, 29.63, 30.81 and 28.89 28 Days 38.66, 41.19, 44.30 and 44.30 60 Days 47.85, 47.26, 48 and 48.59
[47]	0%, 20%, 50% and 100%	0.44	20%	28 Days 41, 44, 42 and 36 50 Days 42, 45, 43 and 38

Table 4. *Cont.*

Reference	QD	Water to Binder Ratio	Optimum	Compression Strength (MPa)
[62]	0%, 25%, 50%, 75% and 100%	0.45	50%	7 Days 30, 30, 35, 31 and 35 14 Days 29, 33, 36, 33 and 36 28 Days 33, 36, 38, 36 and 38
[46]	0%, 10%, 20%, 30% and 40%	0.50	40%	28 Days 45, 50, 50, 60 and 65
[44]	0%, 20%, 30%, 40% and 50%	0.45	40%	M25 37.3, 37.7, 37.4, 39.7 and 38.4 M30 36.5, 38.3, 37.9, 40.1 and 39.2
[79]	0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%	0.48	50%	7 Days 21.33, 22.22, 22.76, 23.25, 23.56, 24.43, 22.76, 20.44, 19.25, 18.66 and 17.78 28 Days 28.58, 29.18, 29.33, 29.48, 29.62, 30.07, 28.58, 26.22, 24.29, 23.25 and 22.66
[63]	0%, 15, 20% and 25%	0.40	15%	7 Days 33, 25, 24 and 23 28 Days 42, 46, 35 and 33
[83]	0%, 10%, 20%, 30%, 40% and 50%	0.40	-	3 Days 3.56, 3.46, 3.25, 3.12, 3.08 and 2.98 7 Days 4.50, 4.25, 4.05, 3.90, 3.75 and 3.55 14 Days 6.50, 5.50, 5.10, 4.80, 5.00 and 4.80 28 Days 8.82, 7.80, 6.70, 6.00, 5.45 and 5.30
[64]	0%, 10%, 20%, 30% and 40%	0.45	30%	7 Days 24.67, 24.85, 25.33, 26.44 and 23.55 28 Days 28.00, 33.11, 33.77, 35.33 and 27.55
[75]	0%, 15%, 35%, 55% and 75%	0.40	35%	3 Days 24.78, 25.85, 29.91, 25.44 and 23.61 7 Days 34.39, 35.05, 35.39, 33.31 and 31.13 28 Days 44.05, 45.18, 43.97, 40.91 and 39.32

The CS with varied quantities of QD at various curing times is shown in Figure 8 along with the strength age relation. The blank mix (control CS) at 28 days is used as the benchmark strength (reference strength). When QD is substituted for the reference material at a 45% replacement rate, the CS is 30% and 47% lower after three and seven days, respectively. The decrease in early age strength (after three and seven three and seven days) with the substitution of QD is due to the fact that the pozzolanic reaction proceeds slowly as compared to the hydration of cement. A similar study also reported that the pozzolanic reaction proceeds slowly as compared to the hydration of cement [84]. Therefore, the early age strength (three and seven days) decreased with the substitution of QD. However, improvement was observed at a later age strength (28 days). According to Figure 8, the reference mix's CS is equivalent to QD at a 45% replacement at 28 days. It may be inferred that using up to 45% of QD in concrete will not have a negative impact on its CS.

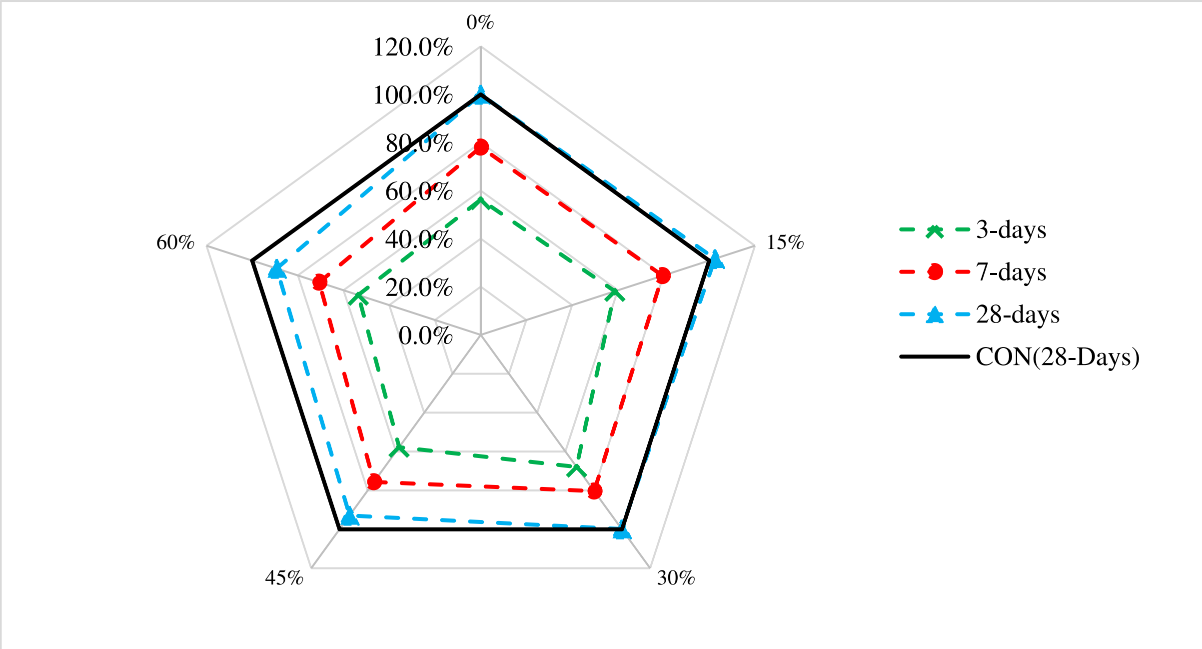

Figure 8. Relative Compressive Strength: Data Source [75].

4.2. Flexural Strength (FS)

Figure 9 and Table 5 demonstrate that, similar to CS, the FS of concrete rose to some extent with the replacement of QD. Higher strength is achieved by the sharp edges of QD particles, which link with cement more effectively than rounded natural sand particles. Comparing compressive stress to FS, the gain is negligible [57]. A researcher looked at the usage of QD in lieu of sand while making concrete. At 50% substitution of sand by QD, the results revealed a maximum improvement in CS (19.18%), TS (21.43%), and FS (17.8%) [79].

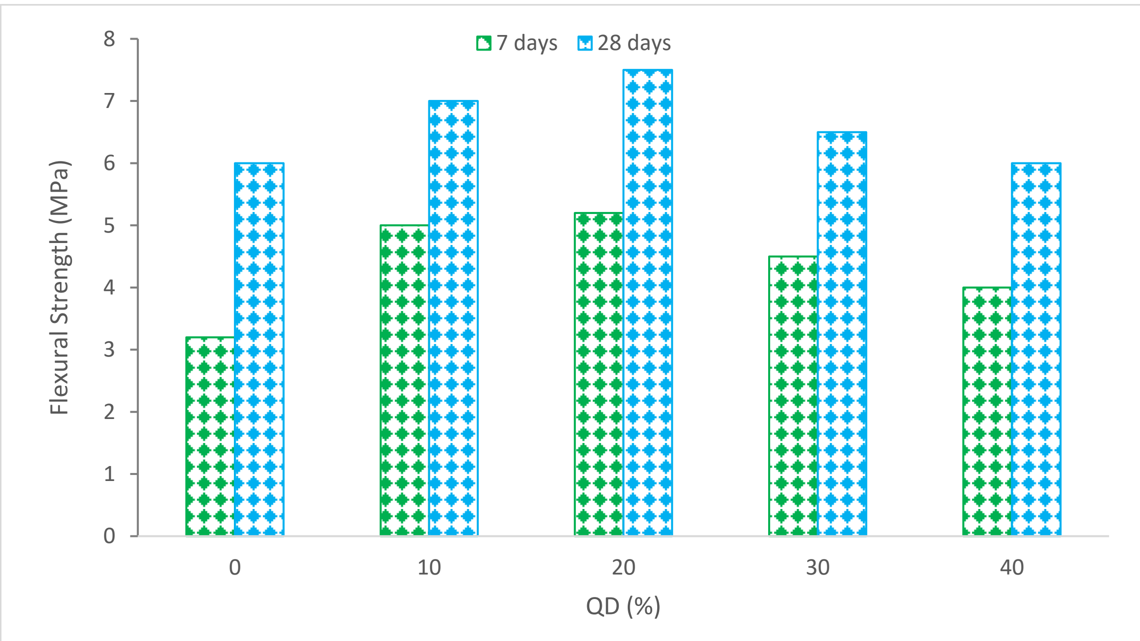

Figure 9. Flexural Strength: Data Source [56].

It was shown that the FS of concrete containing 25% and 100% QD was 2% and 4.3% greater than concrete containing no QD [85]. FS increased by roughly 5.4% when quarry rock dust was used to replace all of the sand in the construction [86]. According to research, the combination of fly ash and quarry rock dust produced good results because of their effective micro-filling capabilities and pozzolanic activity [47]. The research found that split cylindrical tensile and uniaxial compression tests are not as sensitive to aggregate form as the modulus of rupture test. They explained this behavior by the existence of a stress gradient, which slows the cracking process and ultimately causes failure [87].

When compared to rounded natural gravel, concrete with rough-textured and angular-shaped crushed particles has stronger FS [88]. This is because the cement paste and aggregate are better bonded physically and chemically. According to research, using quarry rock dust as a substitute for sand increased the FS and CS of concrete and might have been the result of the fine aggregates' intrinsic strength and the cement paste's strong connection with the fine aggregate [89].

According to research, concrete's mechanical qualities were enhanced when superplasticizers were combined with QD and waste plastic as a filler [62]. The use of QD in lieu of sand while producing concrete was also investigated. The results revealed that the largest improvement in FS (17.8%) occurred at 50% QD substitution of sand [79]. It was shown that the FS of concrete containing 25% and 100% QD was 2% and 4.3% greater than concrete containing no QD [85]. FS increased by roughly 5.4% when quarry rock dust was used to replace all of the sand in the construction [86].

Table 5. Flexural Strength (FS) of Concrete with QD.

Reference	QD	Water to Binder Ratio	Optimum	Flexure Strength (MPa)
[56]	0%, 10%, 20%, 30% and 40%	0.45	20%	7 Days 3.2, 5.0, 5.2, 4.5 and 4.0 28 Days 6.0, 7.0, 7.5, 6.5 and 6.0
[74]	0%, 25%, 50%, 75% and 100%	0.47	-	28 Days 3.9, 2.9, 3.1, 3.5, 3.6 and 3.8
[57]	0%, 50% and 100%	0.53	50%	28 Days 6.25, 6.41 and 6.30 60 Days 6.60, 7.32 and 6.68
[58]	0%, 20%, 25%, 30% and 35%	0.44	30%	7 Days 4.4, 4.2, 4.1, 3.5 and 3.1 28 Days 5.1, 5.0, 4.4, 4.3 and 3.5
[72]	0%, 20%, 30%, 40% and 50%	0.55	30%	7 Days 3.8, 3.5, 2.7, 2.2 and 1.9 28 Days 5.0, 4.8, 4.4, 3.5 and 2.9 91 Days 5.4, 5.1, 4.8, 4.7 and 3.4
[79]	0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%	0.48	50%	28 Days 3.66, 3.78, 3.84, 3.92, 4.05, 4.10, 4.03, 3.88, 3.85, 3.70, and 3.54
[63]	0%, 15, 20% and 25%	0.40	15%	7 Days 12, 11, 9.0 and 8.5 28 Days 12, 12.5, 11.5 and 10.5
[75]	0%, 15%, 35%, 55% and 75%	0.40	35%	28 Days 5.52, 6.25, 5.65, 5.48 and 5.18

Figure 10 depicts the relationship between CS and FS when different amounts of QD are added at varied curing times. The trendline between CS and FS shows a strong relation between CS and FS with an R^2 value of more than 80. As a result, the concrete's FS may be predicted from its CS using the equation shown in Figure 10.

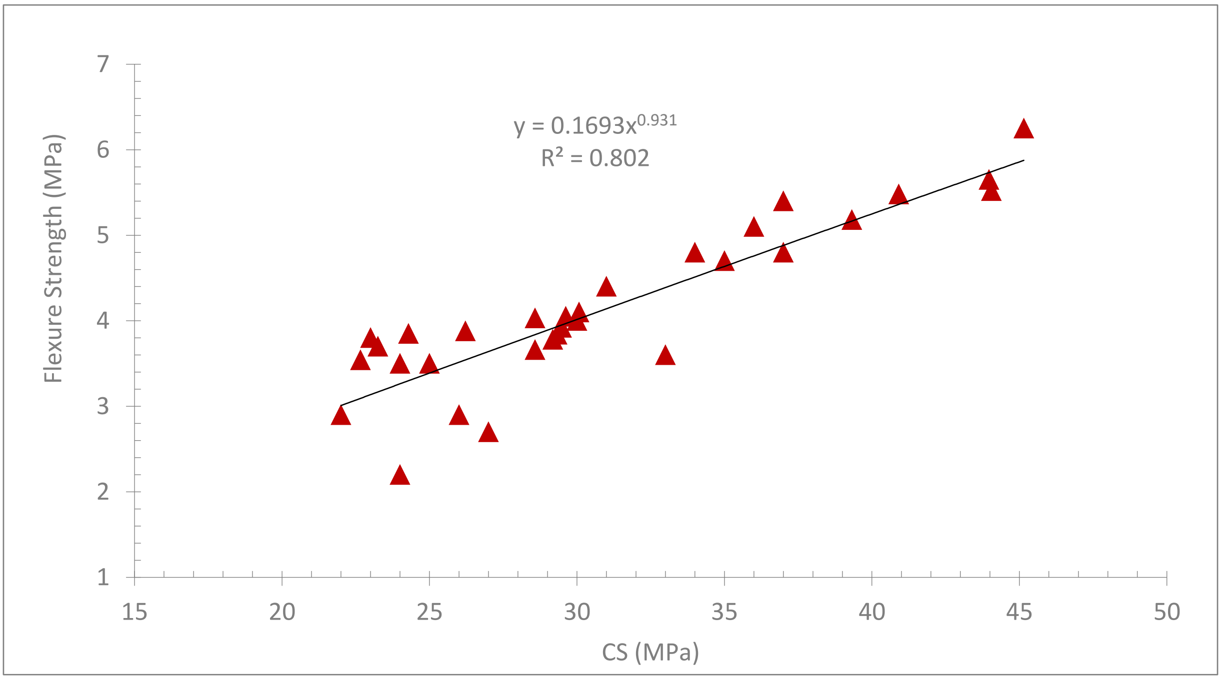

Figure 10. Correlation Between CS and FS: Data Source [72,75,79].

4.3. Tensile Strength (TS)

Figure 11 and Table 6 demonstrate that, similar to CS, TS of concrete rose to some extent with the replacement of QD. The TS rose until 15% of the sand was replaced with QD powder. After that, the TS decreased. This shows that adding QD powder to concrete boosts both the CS and the TS. When QD was substitute 60% as fine aggregate in concrete, a drop of 39% in TS was seen. More so than CS, the quality of the paste affects the TS of concrete. The characteristics of the employed fine particles also have an impact on the consistency of the paste and the interfacial transition zone, which has an impact on the TS of the concrete. Workability drastically decreases as replacement levels rise, which has an impact on how well the mix is compacted. After 15% replacement, the transition zone becomes weaker due to more empty spaces and microcracks in the paste, which significantly lowers the TS [50].

The results of the CS of the concrete mixes at all ages indicated that 20% of QD was the ideal amount of cement and sand replacement. More voids were also produced by replacing the QD at a rate greater than 20%. The need for water rose as a consequence, which decreased the CS [56]. The use of QD in lieu of sand while producing concrete was also investigated. The results revealed that when QD replaced sand to a maximum of 50%, TS increased by a maximum of 21.43% [79]. The strength rises may be ascribed to the compact matrix brought on by the progressive rise of dust up to 35% [90].

Utilizing stone dust gives concrete a uniform mix and may increase its CS, TS, and FS [80]. It has also been claimed that marble sludge powder and QD may completely replace natural sand in concrete. According to research, concrete made with QD had CS and cracking TS that was 14% greater than those of standard concrete [80]. The results show that the specimen mix's TS rises by 13.47% when compared to the standard mortar specimen when sand and cement are substituted for 3% and 35%, respectively, of the stone dust [81]. According to research, adding QD to concrete considerably increased its mechanical qualities, such as its CS, FS, TS, and impact resistance [91].

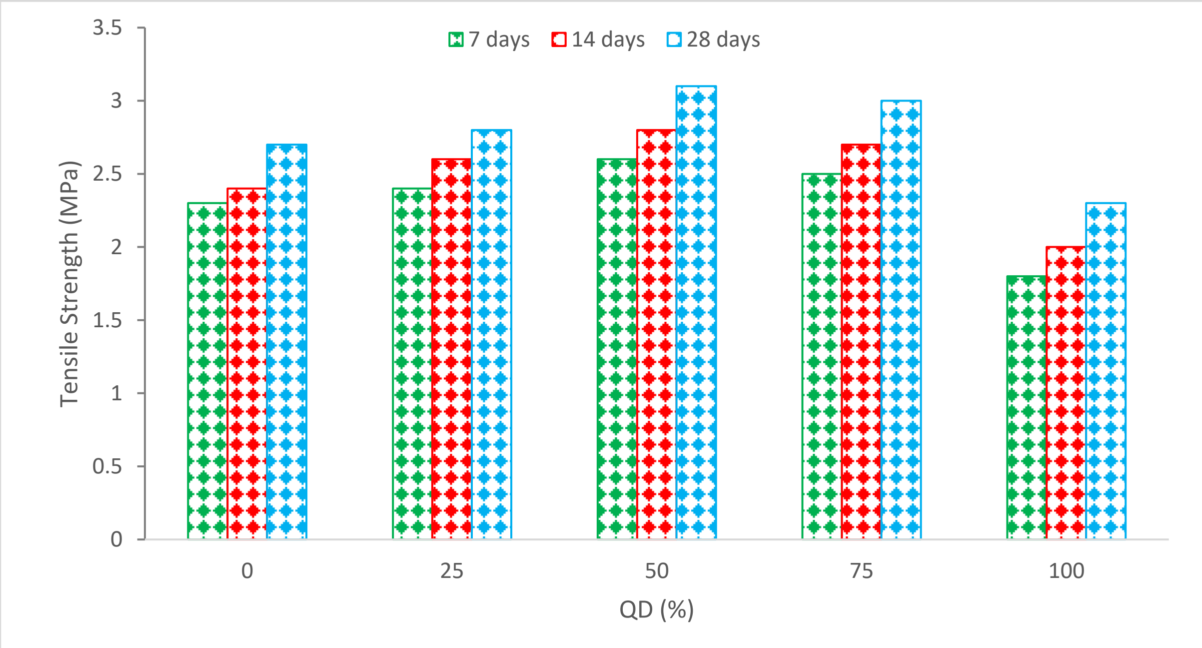

Figure 11. Tensile Strength: Data Source [62].

Table 6. Tensile Strength (TS) of Concrete with QD.

Reference	QD	Water to Binder Ratio	Optimum	Split Tensile Strength (MPa)
[56]	0%, 10%, 20%, 30% and 40%	0.45	20%	7 Days 1.8, 2.2, 2.4, 2.2 and 2.1 28 Days 2.8, 3.2, 3.3, 3.2 and 3.1
[74]	0%, 25%, 50%, 75% and 100%	0.47	-	28 Days 4.2, 3.2, 3.5, 3.8, 4.0 and 4.1
[58]	0%, 20%, 25%, 30% and 35%	0.44	30%	7 Days 2.5, 2.3, 2.2, 2.0 and 2.0 28 Days 2.7, 2.5, 2.3, 2.2 and 2.1
[72]	0%, 20%, 30%, 40% and 50%	0.55	30%	7 Days 2.2, 2.0, 1.7, 1.6 and 1.6 28 Days 2.6, 2.5, 2.4, 2.3 and 2.3 91 Days 3.4, 3.5, 3.2, 3.1 and 3.1
[50]	0%, 20%, 40%, 60% and 80%	0.56	60%	28 Days 2.7, 3.3, 2.6, 2.4 and 1.7
[62]	0%, 25%, 50%, 75% and 100%	0.45	50%	7 Days 2.3, 2.4, 2.6, 2.5 and 1.8 14 Days 2.4, 2.6, 2.8, 2.7 and 2.0 28 Days 2.7, 2.8, 3.1, 3.0 and 2.3
[79]	0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100%	0.48	50%	28 Days 3.17, 3.29, 3.35, 3.44, 3.58, 3.63, 3.56, 3.40, 3.36, 3.20 and 3.03

Table 6. *Cont.*

Reference	QD	Water to Binder Ratio	Optimum	Split Tensile Strength (MPa)
[63]	0%, 15, 20% and 25%	0.40	15%	7 Days 5.0, 4.2, 3.8 and 3.3 28 Days 5.3, 5.2, 4.8 and 3.8
[83]	0%, 10%, 20%, 30%, 40% and 50%	0.40	-	7 Days 1.2, 1.05, 0.75, 0.45, 0.41 and 0.39 28 Days 1.67, 1.35, 1.02, 0.87, 0.78 and 0.70
[75]	0%, 15%, 35%, 55% and 75%	0.40	35%	28 Days 4.24, 5.35, 4.74, 4.60, and 4.38

Research, however, asserted that as the fraction of fine aggregate replaced with QD increases, the TS of concrete diminishes [58]. Similar to the control concrete, a little decrease in TS was seen for concrete containing 40% fine quarry material. This is explained by the fine quarry aggregate's elongated and flaky particle form [92]. The greater surface area of elongated and flaky aggregate adversely affect the flow of concrete, which results in more voids in hardened concrete, leading to less strength.

The relationship between CS and TS with varied quantities of QD at various curing days is shown in Figure 12. CS of concrete affects TS. Concrete's TS is equivalent to 10–15% of its CS. The trendline between CS and TS can be shown in Figure 12. CS and TS have a high association with an R^2 value greater than 70%. As a result, using the equation in Figure 12, one may anticipate the TS of concrete based on its CS.

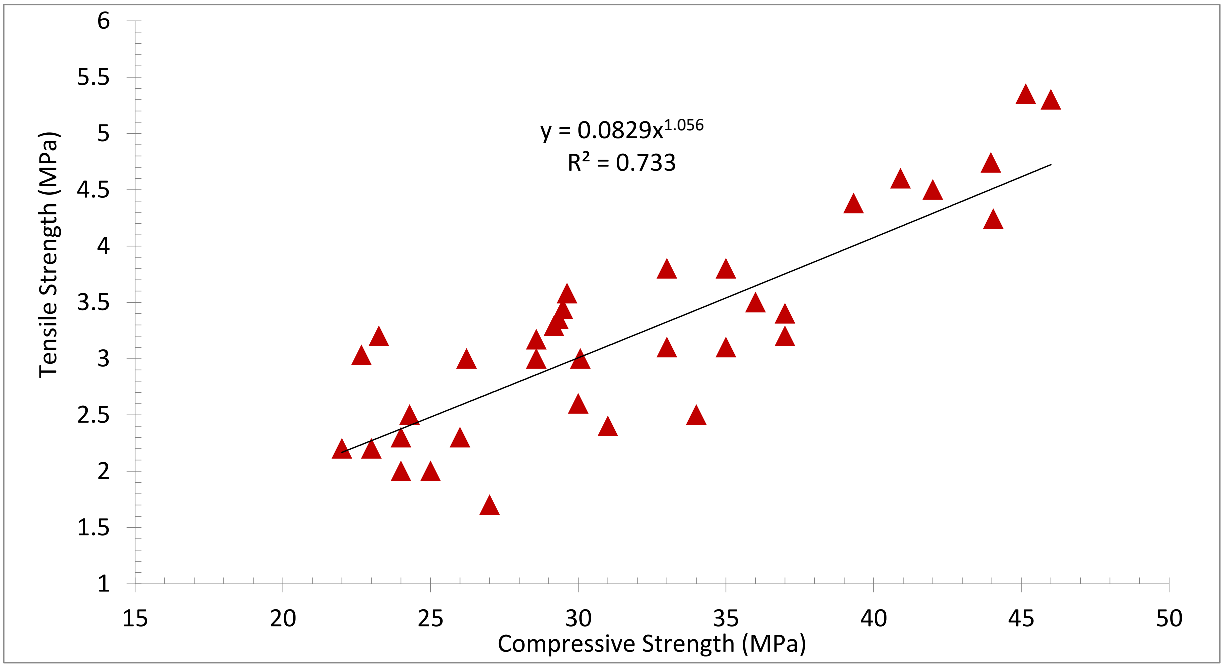

Figure 12. Correlation Between CS and TS: Data Source [63,72,75,79].

5. Durability

5.1. Density and Water Absorption

The relationship between density and water absorption is inverse. Concrete with a high density has fewer voids, which reduces water absorption. Figure 13 illustrates the density and water absorption of concrete with various QDs. QD replacement boosted concrete density by displacing more natural sand.

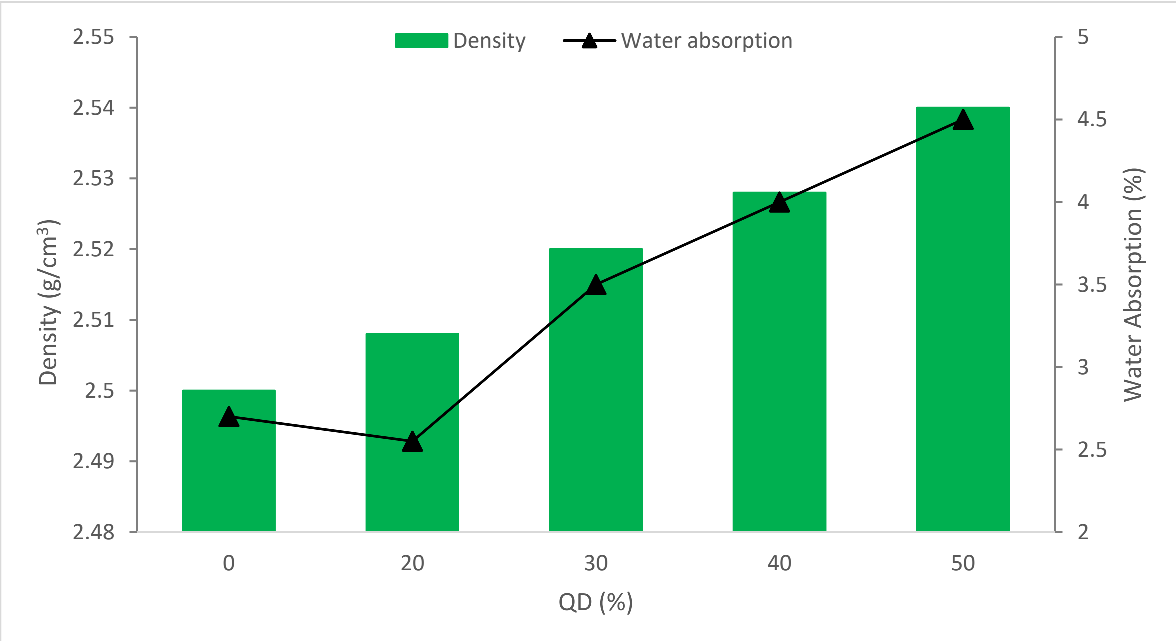

Figure 13. Density and Water Absorption: Data Source [93].

However, QD's water absorption fell by 20%, and as its percentage grew owing to a lack of fluidity, the water absorption increased. The greatest density was achieved using a concrete mix that had a 40% sand replacement level, which resulted in a 3.30% increase in density over the control mix. The greater specific gravity of QD compared to natural sand and the filling action of QD micro-fines to generate a dense microstructure were the causes of the rise in concrete density [93].

Additionally, the research found that the filler ingredients boosted concrete's density by preventing voids in its constituent parts from forming [94]. By substituting various kinds of stone dust for 20% of the sand, the density of the concrete is raised. The density of concrete increases when Nowshera and Dara stone dust is substituted for sand in a 20% ratio as compared to the reference sample [95].

However, the density decreases when pozzolanic elements are increased to between 80% and 100%. It is likely that a larger dosage of pozzolanic materials decreased the density because they were less able to flow. Compared to more workable concrete, the less flowable concrete needed more energy to compress. Therefore, less workable concrete has a higher probability of developing voids, which will negatively impact the density of concrete. According to research, the lack of flowability of filler material caused concrete's density to decline at greater replacement ratios [67].

5.2. Permeability

Concrete's permeability affects its longevity because it controls the rate at which moisture and harsh chemicals may penetrate. Fractured concrete specimens were used by the researcher to assess the concrete's permeability. An initial load (40%of the ultimate load) was applied to the concrete, and it was then examined for water permeability while under steady pressure [96].

The micrograph in Figure 14a was taken of a controlled concrete mix without any starting tension, and it shows the matrix's huge void formations and the weak interfacial zone between the aggregate. When the initial load was applied to traditional concrete, cracking occurred closer to the voids than in the interfacial area, as shown in Figure 14b.

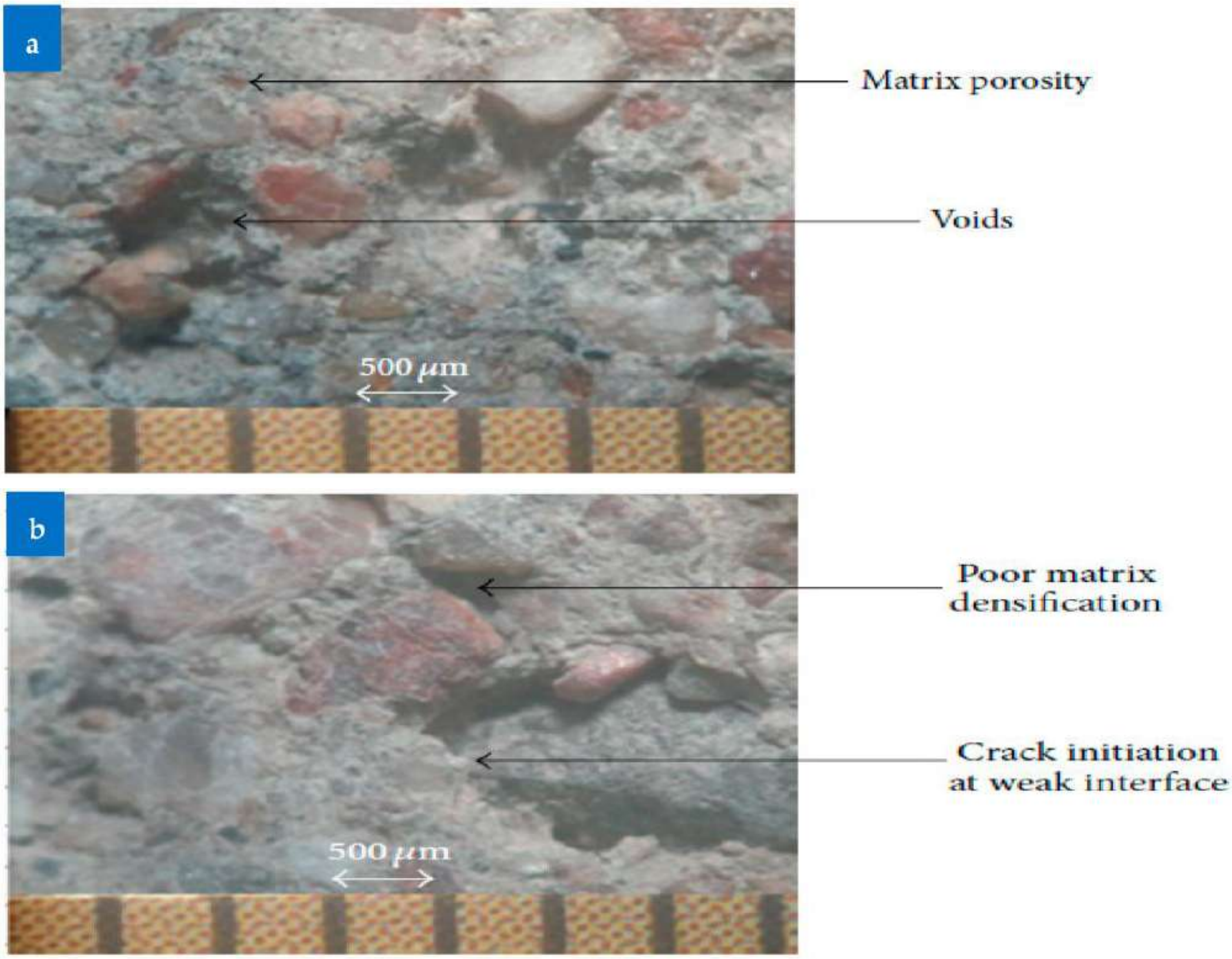

Figure 14. Microscopic view of Conventional concrete (**a**) Without initial stress and (**b**) With initial stress [96].

However, the distribution of smaller particle sizes in the concrete mix made with QD was able to promote matrix densification, as is clearly seen in Figure 15a. Additionally, it can be inferred from Figure 15b that owing to the matrix's larger elastic modulus, aggregate cracking at the interface rather than matrix cracking occurred as a result of the application of initial loading. The microstructural findings further demonstrate that, as compared to traditional river sand concrete mixes, QD replacement concrete more effectively improves matrix characteristics.

Matrix densification may slow the spread of fractures, it is recognized that microcracks near the transition zone are what cause permeability. It may be acceptable to claim that since the microcracks are initially so tiny, the permeability may not be affected. However, when microcracks spread over time as a result of external loads, the permeability of the concrete will grow and a trustworthy assessment of the real permeation resistance of cementitious systems will be given. The findings indicate that using finer QD in lieu of river sand significantly improved the structure's ability to withstand initial stress without developing cracks [96].

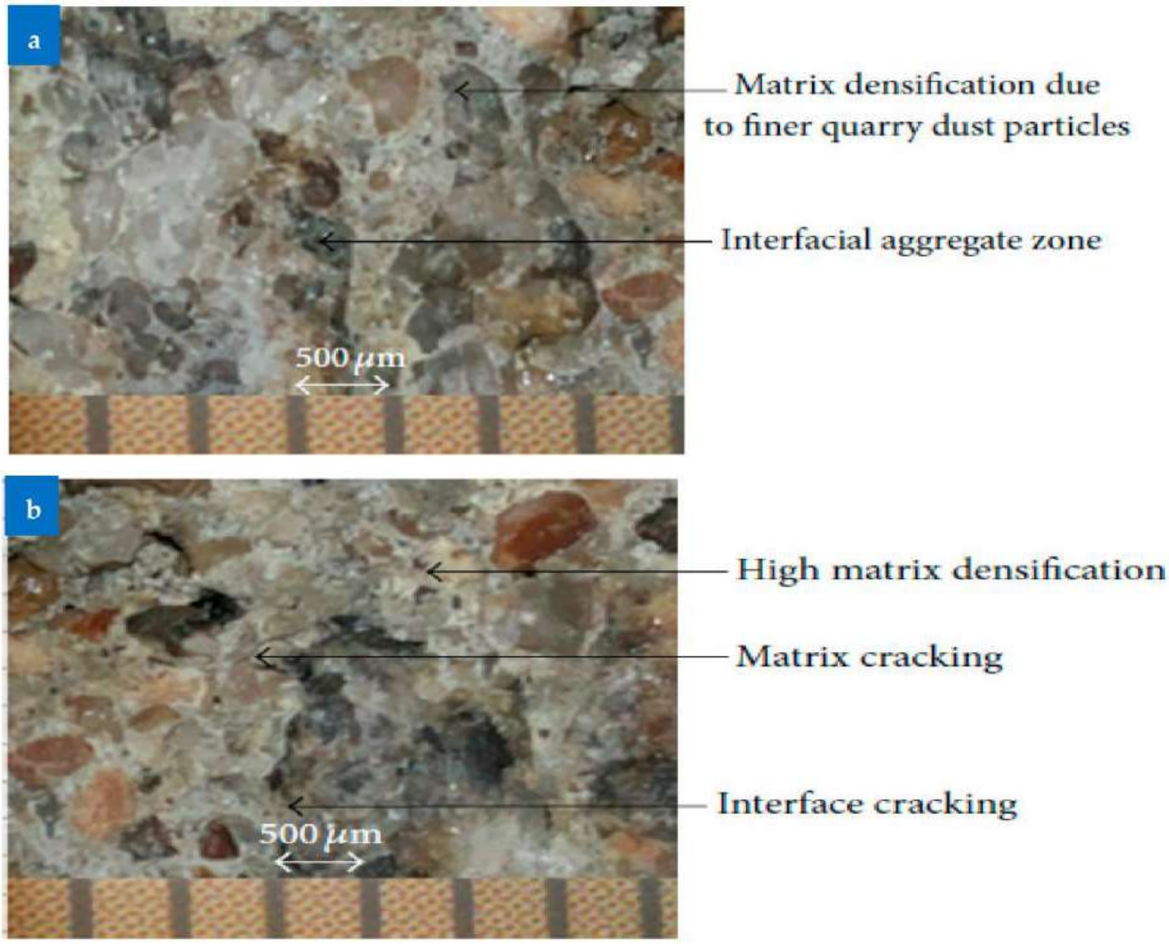

Figure 15. Microscopic view of QD concrete (**a**) Without initial stress and (**b**) With initial stress [96].

5.3. Rapid Chloride Permeability Test (RCPT)

Chloride ingress may cause reinforced concrete buildings to deteriorate. As a result, chloride permeability is a crucial factor that affects how long concrete will last. One of the most crucial requirements for the long-term durability of concrete buildings that are susceptible to reinforcing corrosion is the ability to maintain the permeability of the concrete at the lowest feasible levels. According to the test findings, the average charge traveling through traditional concrete made with river sand had less chloride permeability than concrete with the same cement content but a greater ratio of fine to coarse aggregates (F/C), as shown in Figure 16. Comparing glassy ground granulated blast-furnace slag-infused concrete to ordinary concrete, one study found that the latter had increased resistance to chloride penetration [97].

However, since QD contributes to high matrix densification, adding it to concrete draws less current than using normal concrete. Additionally, it should be highlighted that for QD concrete mixes with larger cement contents, the decrease in chloride permeability was noticeable [96]. According to experimental trends for different concrete mixes including QD, the average charge that passed through concrete specimens for 180 min was found to fall below the low permeability range as defined by ASTM C 1202 [98]. Therefore, it suggests that 100% QD-substituted concrete was impairing the development of the microstructure while maintaining the durability of the concrete.

According to research, after 28 days of curing, concrete with a 20% substitution of stone dust had less chloride ion penetrability for Nowshera and Dara than the control sample. Stone dust particles fill the gaps between aggregates because they are coarser than sand particles. Since there are fewer gaps in concrete, its density rises as a consequence, and the spaces are filled with stone dust [95].

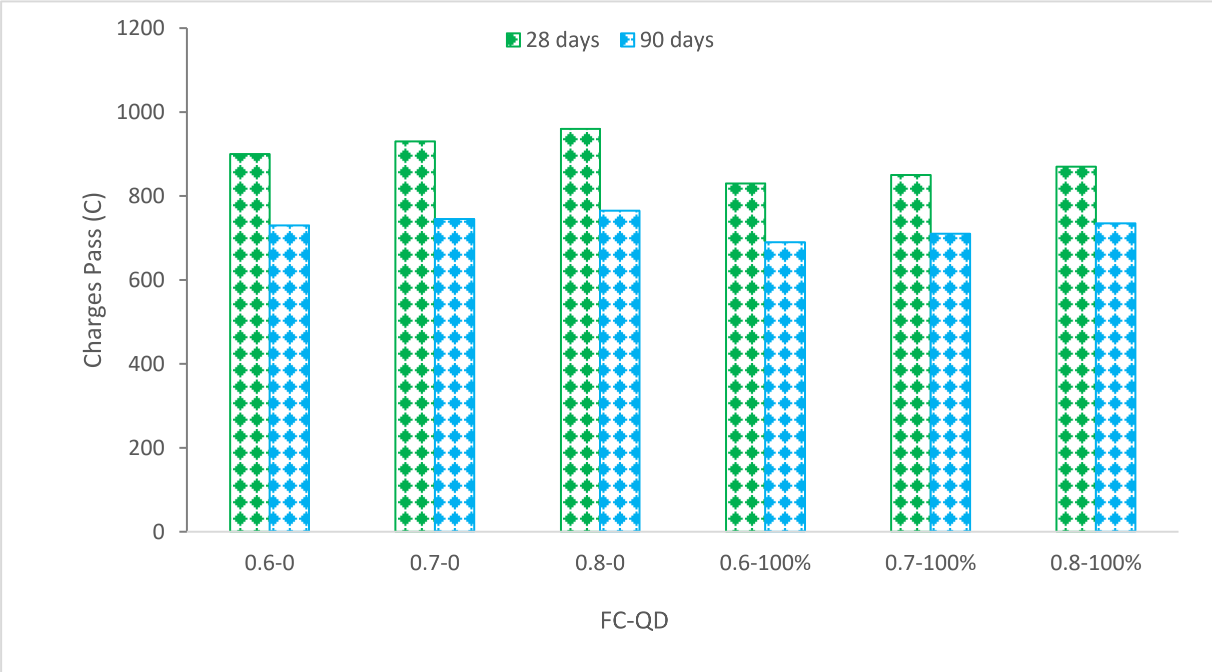

Figure 16. Rapid Chloride Permeability: Data Source [96].

The test findings unavoidably show that the development of pore structures throughout different curing times is what significantly determines the endurance qualities of concrete. As a result, precise microstructural modifications in concrete may be seen when fine fillers are added in the right amounts and the voids are further optimized by efficient packing. It is clear from the concrete that replaced QD that various ratios of finer granular material give an acceptable dense microstructure. Because of this, QD concrete performs better than traditional cement concrete. Due to their inherent porosity, concrete materials exposed to harsh weather degrade more quickly. Since chloride-laden water accelerates the onset of corrosion in concrete with steel incorporated, this test technique is appropriate for determining the permeability characteristics of concrete under harsh environmental circumstances [96].

6. Scan Electronic Microscopy SEM

Figure 17a shows the scanning electron microscopic (SEM) pictures of QD, control mix, 100% sea sand, 50% sea sand plus 50% QD, and 100% QD. Quarry particles are rather angular in form, with sharp edges and pinheaded faces, according to the SEM image analysis of Figure 17a. Interface refers to the region that exists between the aggregate and the hardening zone. Through SEM image analysis, the hardening zone for cement and aggregate may be located. Ettringite was not generated in all the mixtures, as shown by the lack of needle-like features in the SEM pictures. The examination of the control mix in Figure 17b demonstrates solid bonding of the aggregate with the cement, which corresponds to the development of portlandite and calcium silicate hydrate gels. The Mix pictures did not reveal any micro-level voids or fractures.

The sea sand particles in Figure 18 were spherical in form and had smooth surfaces. The size of sea sand particles ranges from 2 to 11 microns in diameter. The distribution of the pore structure is shown to be uneven and loose. It was seen that the cement peeled away from the aggregate, indicating inadequate interfacial adhesion. Low interfacial bonding causes concrete's strength and durability to decrease. The evaluation recommends including certain filler components into the matrix to close gaps and strengthen interfacial adhesion.

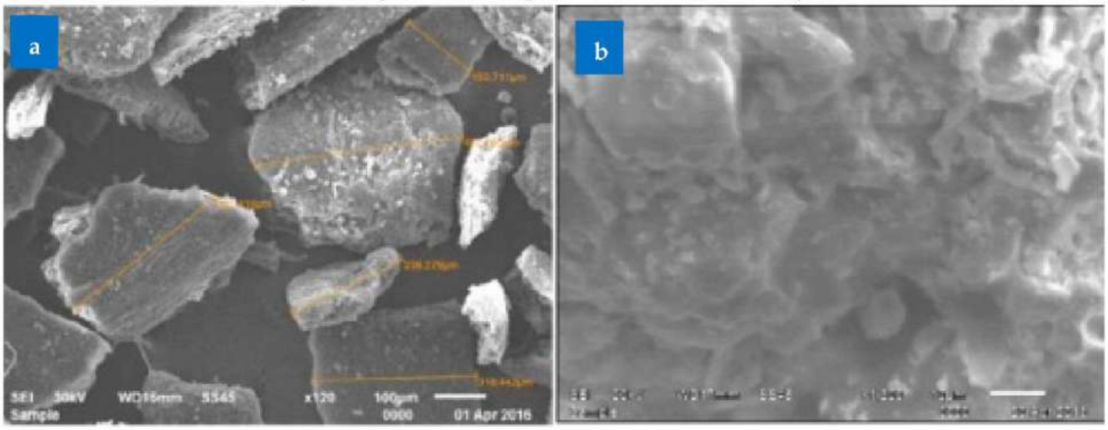

Figure 17. (**a**) QD and (**b**) control mix [74].

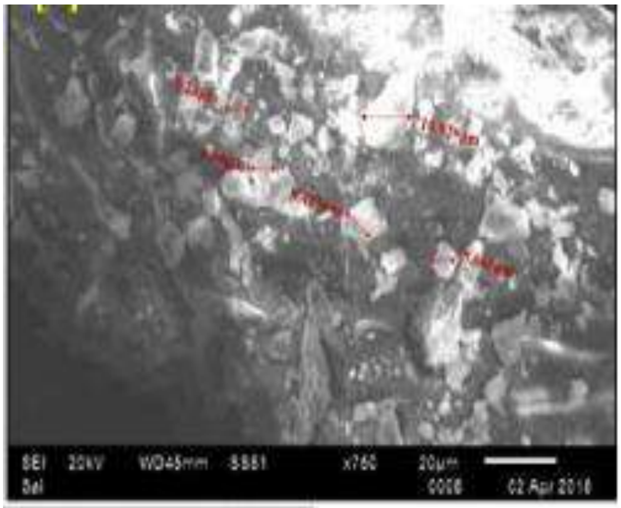

Figure 18. SEM of Sea Sand Concrete [74].

Compact bonding and equal distribution in the pore structure were shown in Figure 19a,b. This could occur because little gaps are being filled, creating a more compact bulk. Additionally, portlandite and calcium silicate hydrate gel formation may be deduced. QD's pozzolanic reaction increased the calcium hydrates silicate gel, which enhanced the microstructure (ITZ). Additionally, portlandite is decreased as a result of the pozzolanic reaction, which negatively impacts the concrete's strength and durability.

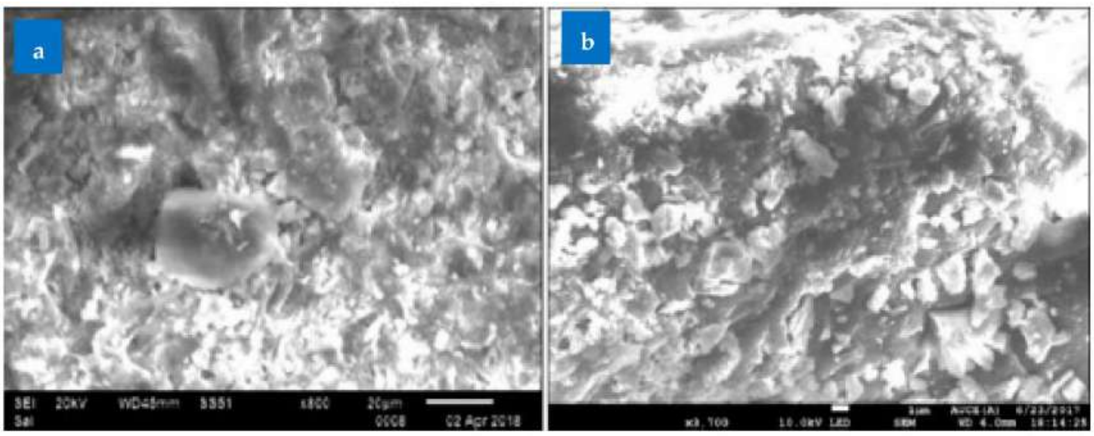

Figure 19. (**a**) 50% sea sand + 50% QD and (**b**) 100% QD [74].

7. Conclusions

Quarry dust (QD), which is generated in significant amounts from quarries and aggregates, is a serious environmental issue. These materials might have positive effects on the environment and the economy if they are used in buildings. The use of the aforementioned by-products as aggregates or cement replacement materials in the production of cement-based building materials has been the subject of recent research studies, which are reviewed in this paper. Based on the analysis, the following conclusion can be made.

The flowability of concrete decreased with the substitution of QD. This is due to rough surface texture and greater water absorption of QD. The mechanical performance of concrete, such as CS, FS, and TS, increased with the substitution of QD. However, the optimum dose is important as the higher dose adversely affects the strength of concrete due to the lack of flowability. The optimum dose of QD varies from 40% to 50%. The density of concrete increased with QD due to filling voids of QD. An increase in density results in less water absorption as well as decreased chloride ions penetration. Furthermore, SEM results reveal that the interfacial transition zone considerably improved with the substitution of QD. The overall review concluded that QD up 40% can be utilized in concrete without any negative effects on strength and durability properties.

8. Recommendation

Although the chemical composition of QD is similar to that of cement, less research focuses on QD as a cement substitution. Similarly, less information is available on shrinkage and creep properties. Therefore, detailed research is required in this area. QD adversely affects the flow properties of concrete, decreasing its strength and durability. A detailed study is required to improve the flow properties of QD-based concrete. A cost–benefits analysis considering the environmental advantages of QD-based concrete should be explored before practically use.

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