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Dolomitic filler in self-compacting concrete: a review

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Abstract

The utilization of fine powders as fillers in self-compacting concrete (SCC) application is widespread, particularly in Europe. The incorporation of these fillers to attain the self-compatibility properties of SCC seems to be cheaper than the use of chemical admixtures. Among the wide range of potential fillers, dolomitic powders, particularly generated as by-products from quarry's processing, are locally available and can be used to produce SCC. Few studies have shown that dolomitic powders can be incorporated in the SCC's mix design, resulting in acceptable fresh and hardened properties of SCC. The particle size distribution and fineness of the dolomitic powder as well as the level of addition are the key factors affecting those properties. The influence of the chemical nature of the dolomitic powder on the properties of SCC, particularly the durability (e.g. alkali-carbonate reaction), is yet to be investigated. Furthermore, more efforts are still required to investigate the use of dolomitic by-products in the production of SCC.

Keywords: Dolomite; Self-compacting concrete; Filler; Alkali-carbonate reaction

1 Introduction

Self-compacting concrete (SCC) is a special type of concrete which flows under its own weight without requiring external vibration for compaction. This is very useful in applications where normal vibrated concrete (VC) cannot be used such as narrow forms and reinforcement congested members. To attain the self-compacting property, it is required that the concrete have adequate viscosity, high deformability and high resistance to segregation. This is can be achieved by adding mineral admixtures (fillers) and/or viscosity modifying agents (VMAs). The former is the main practice in Europe and processed limestone powder is the most commonly used filler in the production of SCC. Moreover, the quarrying process of the production of mineral aggregate results in large amount of fine materials (quarry dust) as a by-product. These significant amounts of environmental wastes pose a real concern to manufacturers due to their impact on the environment, leading to economic consequences.

In fact, the constituents of VC and SCC are alike. Although fillers can be excluded in VC, they play a crucial role in SCC. The term filler could be defined differently according to the users and/or producers as wide variety of industries use fillers in their processes for economic, technical, and/or environmental reasons. The authors would define fillers in the context of SCC as:

> Fine-grained inorganic materials other than cement, mostly less than 125 µm, that could be inert or nearly inert as well as pozzolanic or latent hydraulic and used in order to increase the powder content to improve the rheology of SCC and could affect the fresh and hardened properties of SCC by either physical, chemical and/or physiochemical mechanism.

The last definition implies that there is no limit on the raw materials, including wastes, that can be used to produce fillers for SCC application if they are free of deleterious minerals and have suitable fineness. However, the addition level is strongly dependent on the filler mineralogy and its particle size and shape [1].

Fillers can be used in a wide variety of market aside from the cement and concrete industries including cosmetics, pharmaceuticals, hygiene products, paper, food, adhesives, plastics, sealants and paints and, thus, filler production is a well-established technology worldwide [2]. Most fillers are produced by milling which can result in products above 5 µm in size and the raw materials may require drying before processing. However, ultra-fine filler class can be produced but is perhaps a more challenging aspect of producing fillers on a large scale [3]. The global demand for fillers are predicted to reach about 75 million tonnes in 2024 [4]. The most important applications of fillers are the production and processing of paper, plastics, elastomers, paints and varnishes, as well as adhesives and sealants. The most commonly used filler on the global market is ground calcium carbonate (GCC), with a market share of 34% [5].

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It is worth mentioning that using fillers should be accompanied with occupational health considerations as some fillers such as crystalline silica (quartz, tridymite, and cristobalite) would impose health risk on workers [1]. Therefore, a risk assessment of using a specific filler should be conducted prior to use and all protection measures should be followed to minimise any risk on workers.

For the cement industry, the substitution of clinker by fillers, limestone powder for instance, proportionally reduces the thermal energy and CO_2 emissions in cement production as fillers do not require calcination [1,6]. The interaction between fillers and cement can be on the physical level (filler effect), on the surface chemical level and/or on the chemical level [7]. The physical interaction means that the added fine particles only fill the intergranular pores between cement particles, thereby increasing the density and compactness of the concrete. The surface chemical interaction refers to the creation of nucleation sites by the added filler and thus accelerate the hydration process. The chemical interaction, which is less common in inert material and more common in pozzolanic and latent hydraulic powders, requires that the added fines react with the cement. For instance, some researchers found that limestone filler altered the hydration rate and reacted with cement to form calcium carbosilicate and carbo-aluminate hydrates [5,6]. However, the major effect of limestone filler is believed to be a physical dilution of the binder, thereby reducing the strength. This dilution effect can be effectively compensated by using low water/binder ratio and separate grinding of the filler [1]. Alexander et al found that the use of inert fine fillers improved the strength of concrete due to the development of a densified and homogenized the microstructure, particularly that of ITZ [8]. Similarly, improved strength and durability was reported as a consequence of the pore structure improvement when filler was used [7].

In SCC, the requirements to maintain the cohesion and avoid segregation necessitate the increase of the fine particles content compared to VC. If that is done solely by increasing the cement content, because cement is far finer than aggregates, issues with high heat of hydration and thermal shrinkage would be problematic. Therefore, the addition of fillers not only regulates the cement content but also improves the viscosity of the fluid mixture and its resistance to bleeding and segregation [9]. Additionally, replacing the cement content with a filler reduces the cost and the carbon footprint of the final product [10].

Fillers in SCC can be pozzolanic or non-pozzolanic and can be from natural, industrial or agricultural sources/by-products [11]. The most prevalently used pozzolanic fillers in SCC include coal fly ash, blast furnace slag, ground glass waste and silica fume. In addition, metakaolin, zeolite and rice husk ash have been also used, to less extent [12]. The most commonly used non-pozzolanic filler is limestone powder. However, other non-pozzolanic fillers have been utilized such as marble dust, ceramic waste powder [12], quarry dust [13–16], and olive residue biomass fly ash [17].

Aggregate pits and quarries can be a source of pollution and nuisances to the surrounding natural areas and to local residents as a result of the dust/fines created during processing [18]. The disposal of these waste poses a major economic and environmental threat to the aggregate industry. Therefore, utilizing these wastes in various applications has been studied by many researchers. The use of different types of quarry dusts depending on parent rocks have been investigated as fillers in SCC with numerous conclusions based on chemical and physical properties of the quarry dust as well as the level of addition [13,15,19–23].

As dolomite quarries are abundant, the potential of using the waste generated by the processing of these quarries in SCC is promising. However, there is a lack of comprehensive research or full utilisation of these fillers. Therefore, the present paper will review the use of dolomitic filler in the production of SCC in order to understand the prospective of locally available dolomitic fillers.

2 Dolomite sources and production

Dolomite ($CaMg(CO_3)_2$) is a naturally sedimentary rock formed from the remains of billions of tiny shells and skeletons of microscopic animals or foraminifera in the presence of magnesium as a massive layer on the ancient rock [24]. Rocks containing only 10–50% of the mineral dolomite are called dolomitic [25]. Formation of dolomite can occur via two possible mechanisms: i) direct precipitation from solution to form primary dolomite, and ii) dolomitization process in which calcite undergoes dissolution supplying the Ca^{2+} ions followed by the precipitation of dolomite from a solution rich in Mg^{2+} ions [26]. Most, if not all, dolomite is a replacement of pre-existing limestone through the dolomitization process [25]. The dolomitization can be incomplete and therefore rocks termed 'dolomite' are usually a combination of dolomite, dolomitic limestone and limestone. Dolomite is an end-member mineral consisting of alternate layers of calcite $CaCO_3$ and magnesite $MgCO_3$ and theoretically, it crystallizes in the rhombohedral unit cell [27]. Divalent Fe substitution for Mg^{++} in dolomite to form solid solutions toward ankerite ($CaFe(CO_3)_2$) is not uncommon [28]. Dolomites bearing manganese, zinc, lead, strontium as well as cobalt and nickel also exist [27]. Dolomite reserves are ample worldwide, and their processing operations are considered low in cost, less toxic and environmentally friendly [26].

Dolomite decomposed at high temperatures in two consequence stages according to equations 1 and 2: at lower temperature (~750 °C [29]), calcite and magnesium oxide form whereas calcite decomposes at higher temperature (~840 °C [29]) to form calcium oxide [30].

$$CaMg(CO_3)_2 \rightarrow CaCO_3 + MgO + CO_2 \quad (1)$$

$$CaCO_3 \rightarrow CaO + CO_2 \quad (2)$$

Dolomite is extracted by surface quarrying using primarily drill and blast techniques but breaking by impact hammer can be used. Due to the discrepancies in chemistry and hardness of stone, the dolomite is selectively quarried at several distinct levels, known as 'benches'. Processing can be basically divided into crushing, screening, grading and storage prior to loading and transportation [25].

About 80% of the oil and gas reservoirs in North American carbonate rocks are in dolomites and up to 50% of the world's carbonate reservoirs are dolomites [31]. Permian dolomites are the main source of dolomite in the UK, but dolomite also occurs in some parts of the Carboniferous limestone sequence. However, in most areas the dolomitization is not sufficiently extensive, or of consistently high grade, to form a resource of industrial dolomite. Unlike limestone sources in the UK, dolomite resources mostly impure and may contain 0.2-0.25% Fe_2O_3. In the UK, the total production of dolomite, in 2014, was 3.75 million tonnes, most of which was used in construction and the remaining in industrial/agricultural uses including as a filler [32].

3 Properties and characterization of Dolomitic filler

Pure dolomite has an MgO content of about 40%. But most quarries would have a combination of dolomite, dolomitic limestone and limestone [25]. Dolomite is relatively soft and easily crushed to a fine powder. Dolomite when pure is colourless or pearly white but it sometimes has pink, green, gray, brown and black colors depending on the chemical composition and impurities. Dolomite has a Mohs hardness of 3.5 to 4 and is sometimes found in rhombohedral crystals with curved faces. The reaction between dolomite and cold, dilute hydrochloric acid is very week; however, if the acid is warm or if the dolomite is powdered, a much stronger acid reaction will be observed. Some physical properties of both limestone and dolomite are presented in Table 1.

Table 1. Some properties of Limestone and dolomite [33].

Property	Limestone	Dolomite
Molecular weight	100.1	184.4
Specific gravity	2.65	2.85
Moh's hardness	3	3.5
Decomposition temperature (°C)	From 875	From 400
Refractive index	1.59	1.6
% brightness	88-96	88-95

4 Uses of dolomite

Dolomite has many industrial uses and can be used as raw dolomite or processed/calcined into a wide range of products (see Table 2). It is the raw material for a large variety of construction, agricultural, environmental, and industrial materials [34]. Large volumes of dolomite are used in construction as aggregate in concrete or asphalt [35] and it serves as a flux in metallurgy [25]. Dolomite can be decomposed to produce magnesia (MgO), which extensively used in manufacturing the most important products of the magnesium compound industry such as alloys, die casting, desulfurisation of iron and steel, refractories, pharmaceuticals, glass industry, fertilisers, etc. [3]. One interesting product is MgO-based expansive agent added to cement/concrete to reduce their shrinkage [36–39]. Dolomite is effective also as a parent-sorbent for high temperature CO_2 capture [40].

Table 2. Summary of uses of dolomite.

Application	Purpose
Adhesives and sealants	As a filler and as a viscosity control agent
Construction	As a filler for concrete, grout, asphalt and roofing materials and as aggregate It can be used as a dimension stone It can be used as a ballast for railway tracks
Magnesium and magnesium compounds	For production of magnesia
Environment (desulphurization of flue gas)	As a natural alkali source and/or fire suppressant It can be used as beds in trickling filters in sewage disposal plants
Fertilizer and agricultural liming	As a magnesium source and/or filler And for rehabilitation of over-acidified lands and waters It can be used as a neutralising and absorbent of organic wastes
Ceramics	Kiln control
Paint and surface coatings	An aid to pigmentation, extenders and/or finish aids
Paper	As a filler, coating pigments or acidity control agents
Plastic	As a filler and to improve rheology, mechanical properties and finish
Rubber and elastomer	As a fillers or extenders
Flux	As a flux in smelting metalliferous ores
Glass	As an important constituent of the batch (20-30%)
Refractory	As a basic refractory in making steel
Rock dusting	As a dust applied to the walls, roofs and floors of coal mines to prevent or check dust explosions

5 Use of dolomitic filler/aggregate in Self-Compacting Concrete

Research concerning using dolomite powder for production of SCC is very rare. The influence of dolomite powders, either commercially available or extracted from aggregate processing waste, on fresh and hardened properties of SCC is dependent on the physical properties of the filler and content, the replacement types and the mix proportions and constituents of SCC as can be seen in Table A1 in Supplemenatary Materials. For instance, the addition of dolomite powder to substitute slag in PC-slag systems, on one hand, did not change the hydration rate but led to a significant reduction of heat, particularly at 70% and 100% replacement level, while, on the other hand, the addition of dolomite powder to substitute fly ash or a mixture of fly ash and slag in PC-fly ash and PC-fly ash- slag systems, respectively, resulted in significant acceleration of the hydration rate and increased the total heat released [10]. This behavior was attributed to the physiochemical properties of the fillers compared to slag and fly ash [10]. It was revealed that replacing the cement in a dolomite-based SCC with fly ash and limestone would effectively reduce the total heat liberation, while the use of metakaolin had no effect on the total heat release of these mixes [41]. The particle size distribution of the dolomite is a key factor governing its effect on both fresh and hardened properties of cement-based composites [42]. Vaitkevičius et al [43] suggested that using up to 15-20 % dolomite as a per cent of cement mass in the production of SCC would not compromise the mechanical strength and the self-compatibility requirements. The incorporation of ground dolomite would increase the robustness of SCC [44]. The use of dolomitic filler in SCC was recommended in many standards and guidelines [9,35,44,45]. Detailed review of the effect of dolomite powders on fresh properties, hardened properties and durability of SCC is discussed in the following subsections.

5.1 Fresh Properties

Sahmenko et al. [46] used a dolomitic quarry by-products having a maximum size of 8 mm and containing 26% of fines less than 63 µm to produce normal concrete (NC), high-performance self-compacting concrete (HPSCC) and Architectural concrete (AC) with various w/c ratios. The dolomite by-product represented 60%, 40% and 100% of the total aggregate in NC, HPSCC and AC, respectively. They reported that the HPSCC reached a slump flow of 590mm by adding 1% SP and therefore it can be classified as SF1 according ENFRAC 2005 [46]. They explained that the angular shape of the dolomite by-product may cause the limited flowability. However, the obtained workability is acceptable as a SCC.

Rudžionis et al [47] examined the use of dolomite sifitings of 0/2 fractions as a partial replacement to aggregate (7-28% replacement levels) on the properties of SCC. The mixes were designed with a slump flow target between 620 – 650 mm and having a w/c of 0.55 and SP dosage of 1% of the cement content and by adding small quantities of viscosity modifying agent (stabilizer). They reported that the use of the dolomite siftings up to 14% increased the slump flow diameter without increasing the water content and beyond this percentage the slump flow diameter slightly decreased. The improvement of workability was explained by the effect of ellipsoid to sphere shape of the dispersive particles of dolomite siftings as examined by stereo microscope [47].

Martín et al [48] compared between a commercial dolomitic filler, not commonly used, and a reclaimed waste filler from bituminous mixtures. The dolomitic filler was a commercial fine-grained material from the crushing of marble from Macael (Almería) and XRD tests revealed that this filler is mainly dolomite with small quantities of calcite and quartz. The results of V-funnel and slump flow indicated that both fillers satisfy the requirements of SCC in regards of fresh and hardened properties measured with commercial dolomite filler mixes performed slightly better in all aspects. Other tests such as L-box test and slump flow test with J-ring were also carried out and showed satisfactory results. The fresh concrete density of the mixes containing commercial dolomite filler was about 2442 kg/m^3 while the air content was measured to be 1.4%, which well below the 6% permissible level.

The incorporation of 7% and 14% of dolomite siftings of 0/2 fractions significantly reduced the segregation index while increasing the percentage to 28% markedly increased the segregation index [47]. Heirman and Vandewalle [49] extensively studied the effect of various fillers, including 1 dolomite filler, 7 limestone fillers, 2 fly ashes and 2 silica fillers, on the workability of SCC. The source of the dolomite filler was not declared but the dolomite filler used was relatively coarser than all other fillers with a fineness of 236 m^2/kg measured according to Blaine method described in EN 196-6 and d_{50} of 37.1 µm. They found that the slump flow diameter and T_{500} of concrete containing dolomite filler were 640mm and 1s, respectively, which are appropriate according to the author's criteria. The range of those two parameters for all mixes were between 630 and 678 mm for slump flow and between 1 to 3 s for T_{500}. The time necessary for the concrete mix with dolomite filler to flow out of a V-funnel was 6 s (the acceptable range 5-15 s). In regards of the U-test filling height, SCC with dolomite filler had the highest filling ability of 329 mm (the acceptable level is higher than 300 mm).

Nguyen and coworkers [10,50] explored the possibility of replacing supplementary cementitious materials with dolomite powder (DP) to produce self-compacting concretes and mortars (SCC/SCM). Their findings revealed that the addition of DP to PC-slag, PC-fly ash and PC-slag-fly ash mortars decreased the SP dosage required to reach the targete flowability measured by mini-slump and mini V-funnel [10,50]. In contrast, Barbhuiya [51] reported that the addition of dolomite powder necessitates the increase of SP dosage in PC-FA-DP SCC to maintain the target flowability (550-650mm), except for the mix with 25% DP. Based on the compressive strength of the mortars, Nguyen and coworkers [10] proceeded with the same systems with the addition of 30% dolomite powder as partial replacement of the pozzolanic materials in each system to produce SCC. The fresh properties of S-DP-30, S-FA-DP-30 and FA-DP-30 SCC were tested with various tests. Their findings indicated that all systems has acceptable fresh properties with S-FA-DP-30 SCC mix being marginally superior to other systems [10]. Similarly, another study found that, among all replacement levels, the addition of 25% of DP to substitiute fly ash would be suitable for SCC production [51]. The SCC mix with 100% DP as filler had a slump flow of 550 mm, time increase of V-funnel after 5 minutes of ~3.9s and L-box ratio of ~0.68 c as shown in Table 3. Gabrijel et al [41] produced an SCC using commercial dolomite filler and aggregates with a slump flow of 732mm, a T_{500} slump flow of 2.08s, L-box ratio of 0.94, segregation resistance of 5%, a unit weight of 2499 kg/m^3 and an air content of 1.9%. The physical and chemical properties of the filler and aggregates used were reported elsewhere [52].

Table 3. Summary of fresh properties of SCC incorporating dolomite powder (DP) and fly ash (FA) [51].

Mix ID	Dolomite powder percentage (%)	Slump flow (mm)	V-funnel flow time (s)	L-box ratio
Mix 1	0	~645	~5.9	~0.75
Mix 2	25	~630	~5.8	~0.78
Mix 3	50	~555	~5.5	~0.73
Mix 4	75	~555	~6.2	~0.74
Mix 5	100	~550	~7.8	~0.68

Billberg [53] studied the effect of 7 commercial dolomite fillers on the rheological properties, yield stress and viscosity, of two types of cement (labelled as Cement S and D) using a fine mortar. Cement S constitutes of 57% C_3S, 13% C_2S, 8% C_3A, 7%C_4AF, 3.4% SO_3, 3.6% Mg0 and 1.1% alkalis and has a blaine surfaces of 360 m^2/kg while Cement D constitutes of 53% C_3S, 23% C_2S, 1.6% C_3A, 14%C_4AF, 2.1% SO_3, 0.9% Mg0 and 0.47% alkalis and has a blaine surfaces of 300 m^2/kg. The fillers all has the same chemical composition but differs in the particle size distribuiton. He demonstrated that as the median particle increased to 40 µm both the yield stress and viscosity decreased for both cements as shown in Fig. 1. This was explained by the increase of specific area required wetting by increasing the filler fineness, thereby increasing the shaear resistance of the suspension. The rheological values for the fillers with median particle size greater than 40 µm were similar to those of 40 µm, indicating that no further decrease occurred.

Some researchers have used dolomitic aggregates to produce SCC. For instance, Cuenca et al. [17] examined the effect of olive residue biomass fly ash as a replacement to limestone filler in SCC made with dolomitic sand and gravel and concluded that this fly ash can be used to manufacture SCC. Similarly, Sadek et al. [54] produced a SCC with dolomitic coarse aggregate having a slump flow and V-funnel time between 675-765mm and 7.6-10.1 s, respectively.

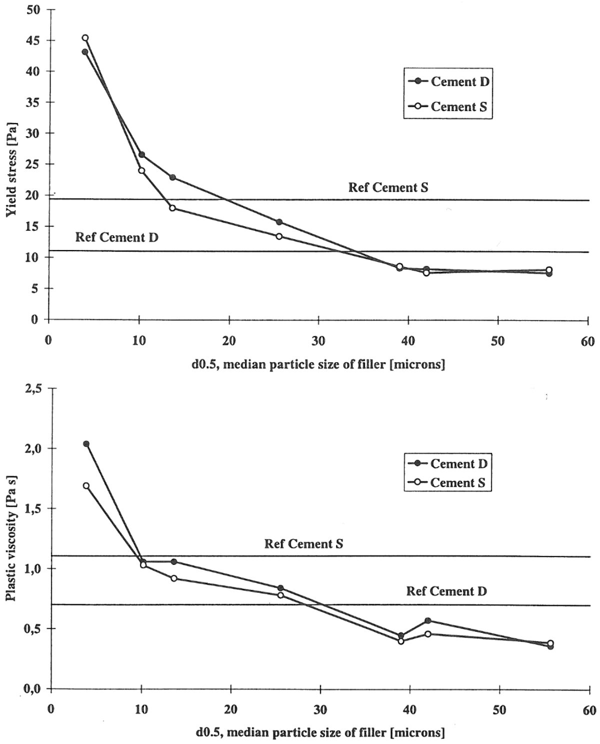

Figure 1. Relationship between median particle size of dolomitic filler and rheological properties: (top) Yield stress; (bottom) Plastic viscosity [53] (See Cement S and D properties above).

The data from the previous literature analysed in terms of the dolomite filler content as a percentage of the total powder content as can be seen in Fig. 2. Other relationships between the filler properties and fresh properties of SCC, e.g filler fineness and flow diameter, could not be established because of the lack of sufficient data. The figure shows the relationship between the dolomite filler percentage and the slump flow diameter. The dolomite filler percentage varies between 10% and 50% and the flow diameter changes between 550mm and slightly above 800mm. The data implies a filler content up to 40% is likely to result in an acceptable flowability. However, as the data is not statistically representative, definite conclusion will require more testing and data.

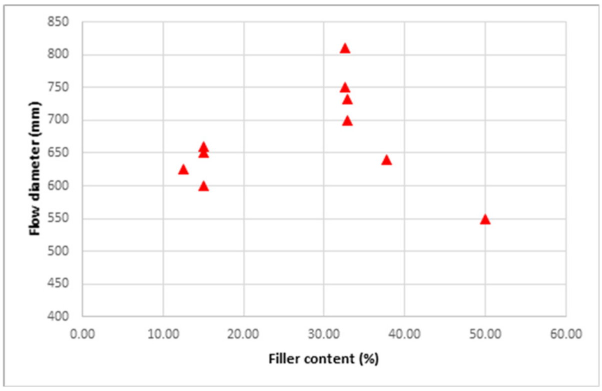

Figure 2. Analysis of flow diameter data from literature as a function of the dolomite filler content as a percentage of the total powder content.

5.2 Hardened Properties

The compressive strength of high-performance SCC studied by Sahmenko et al. [46] using 40% of dolomite by-products (0-8 mm) as a replacement to aggregate was higher than 70 MPa at 28 days and higher than 80 MPa at 56 days while the tensile splitting strength at 28 days reached 4.6 MPa. Similarly, Rudžionis et al [47] showed that the replacement of aggregate by dolomite siftings up to 14% increased the compressive strength and the modulus of elasticity. However, it was noticed that the strength was reduced as the dolomite siftings replacement level increased, Fig. 3. The authors attributed the improvement of strength up to 14% of replacement to the provision of $CaCO_3$ by the dolomite siftings which partially react with aluminates compounds, making a new calcium carboaluminate complexes, thereby inosculating together make the cement stone stronger [47]. However, other researchers believed that the improvement of the strength can be due to the ettringite stabilization and the formation of carbonate AFm phases [55] or the formation of hydrotalcite [56]. SCC made of dolomitic aggregates and limestone filler can reach higher than 40 MPa at 28 days [17].

Martín et al [48] obtained a 50 MPa SCC with the use of 145 kg/m^3 commercial dolomite filler and 300kg/m^3 cement using w/c of 0.55 and SP dosage of 1.8%. In another study, the authors concluded that compressive strength development of SCC containing dolomite filler was analogue to those containing limestone fillers [49]. Moreover, they reported that SCC with dolomite filler developed higher strength than a reference vibrated concrete. The 1-day cube strength of the SCC mix was 10 MPa while the reference mix had 1-day cube strength of 9.2 MPa and other SCC mixes with different fillers varied between 8.1 – 16.2 MPa. The 28-day and 90-d cube strengths of dolomite filler mix were 59.7 MPa and 69.4 MPa, respectively. The long-term strength (i.e 90-d strength) of the SCC mix with dolomite filler was slightly lower than the highest strength of 70.1 MPa [49]. Rukavina and co-workers [41,52,57] obtained a 2-d cube strength of 57.3 MPa, 28-d cube strength of 81.1 MPa, a 365-d cube strength of 104.2 MPa and a 28-d static modulus of elasticity of 48 GPa for dolomite-based SCC. The authors revealed that replacing the cement in their mix design with metakaolin increased the strength and modulus of elasticity with the increase of the metakaolin content, whereas replacing the cement with either fly ash or limestone lowered both values.

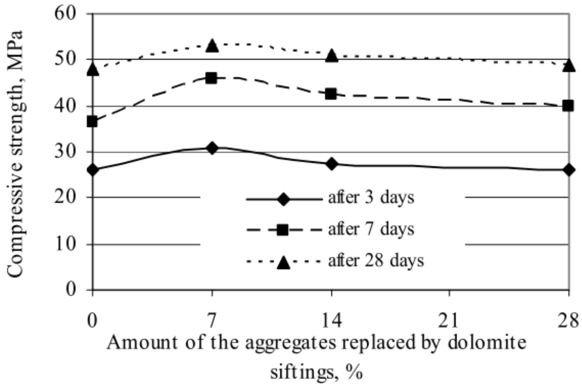

Figure 3. Development of concrete compressive strength as a function of the amount of replaced aggregates by dolomite siftings [47].

Soroka and Setter [58] investigated the effect of filler content and fineness on mortar strength. They used limestone, dolomite and basalt fillers with various fineness to replace 10-40% of PC. Their findings indicated that the limestone and the dolomite had similar effect on mortar strength, whose strength increased as both the fineness and filler content increased while the incorporation of basalt yielded even higher strengths which explained by the pozzolanic effect of Basalt used. At all ages, compressive strength of mortar containing these fillers were higher than the control mortar of pure PC. They attributed the effect of filler primarily to the acceleration of hydration occurred in the presence of the filler and partly to the densified mortar [58]. The addition of 30% dolomite powder to substitute slag and fly ash in PC-slag, PC-fly ash and PC-slag-fly ash mortars improved the compressive strength [10,50]. Therefore, Nguyen et al. [10] examined the mechanical properties of PC-slag, PC-fly ash and PC-slag-fly ash SCCs using 30% dolomite powder (DP) as a replacement to the pozzolanic material in each mix. The obtained compressive strength were in range of 35.4-46.4 MPa and 43.9-63.1 MPa at 7 and 28 days, respectively. The authors measured the strength efficieny of the cement in the presence of DP and concluded that addition of DP increased the strength efficiency to 0.15 - 0.20 MPa/(kg m^{-3}) which is higher than that of 0.11 - 0.14 MPa/(kg m^{-3}) normally used in practice on SCC design. It was also shown by means of ultrasonic pulse velocity that the SCC systems including 30% DP had high quality to be used in concrete structures.

SCC mixes containing various contents (0-100%) of DP filler as a replacement to fly ash, used as a filler with fixed PC content and w/b ratio at 290 kg/m^3 and 0.38, respectively, showed a slight loss in compressive strength with the addition of DP, particularly at 28 days. The compressive strength reported ranged between 33.22 to 37.91 MPa as shown in Table 4. The loss in strength was attributed to the pozzolanic nature of fly ash, causing a reaction between glassy phase in the fly ash and calcium hydroxide generated from the hydration of Portland cement, thereby leading to the formation of additional C–S–H gel and higher strength [51]. This explanation, in our opinion, is somewhat confusing as the pozzolanic reaction would contribute to the strength gain at later ages (beyond 28 days) which is not provided in the study. Further, the variation in strength is relatively low and could not be considered statistically significant as the author did not provide error bars of the measured strength, particularly mixes with 100% DP gained marginally higher strength than mixes with 75% DP at 28 days. Therefore, more information on the purity and physical properties, particularly the particle size distribution and surface condition, of DP is required to understand its effect on the strength.

Table 4. Summary of hardened properties of SCC incorporating dolomite powder (DP) and fly ash (FA) [51].

Mix ID	Dolomite powder percentage (%)	3-d strength (MPa)	7-d strength (MPa)	28-d strength (MPa)
Mix 1	0	~18	~26	~38
Mix 2	25	~17	~25	~35
Mix 3	50	~17	~22.5	~34
Mix 4	75	~16	~20.5	~32
Mix 5	100	~15	~21	~33

The compressive strength data from the previous literature analysed in terms of the dolomite filler content as a percentage of the total powder content as can be seen in Fig. 4. The 28-day strength largely varied between as low as 30 MPa to as high as 85 MPa.

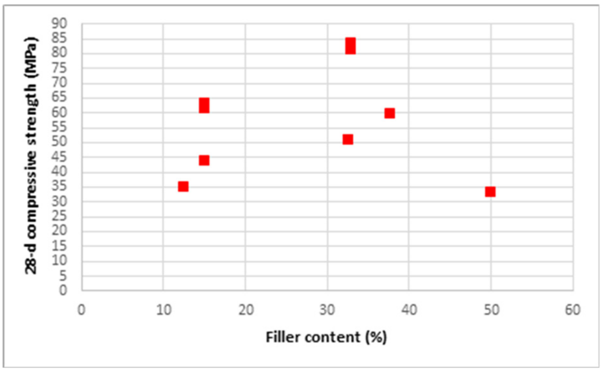

Figure 4. Analysis of 28-day compressive strength data from literature as a function of the dolomite filler content as a percentage of the total powder content.

The drying shrinkage of SCC samples incorporating dolomite siftings as partial replacement to sand was reported to be reduced compared to control samples at all replacement levels studied as can be seen in Fig. 5. However, the shrinkage increased as the dolomite siftings percentage increased. This behavior was explained by the measurement of open capillary pores average rate (λ) which was found that the addition of 7% dolomite siftings decreased λ from 2.29 to 1.96 while adding more dolomite siftings increased the rate. Moreover, the authors observed that the mass loss of mixes including up to 14% of dolomite siftings was 37% lower than the control mix with no dolomite siftings and observed that the tension strains of these mixes increased compared to the control, allowing the SCC to maintain its elastic properties under larger strains [47]. The behavior of drying shrinkage of SCC with various fillers including one dolomite filler were compared with normal vibrated concrete by Heirman and Vandewalle [49]. They showed that SCC developed higher shrinkage strains than the reference concrete and dolomite SCC mix had the second largest shrinkage strain of ~550 microstrain after 56 days.

The autogenous shrinkage of dolomite-based SSC were less than 0.20% [41]. It was found that replacing the cement of those dolomite-based SSC by metakaolin, fly ash and limestone resulted in increase in the autogenous shrinkage, unchanged in the autogenous shrinkage and reduction in autogenous shrinkage, respectively [41].

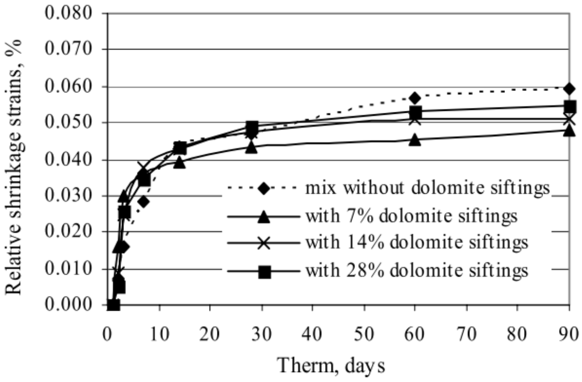

Figure 5. Development of concrete shrinkage strains as a function of the amount of replaced aggregates by dolomite siftings [47].

5.3 Durability

This section will discuss the available data on durability behavior of SCC containing dolomitic fillers. The porosity of SCC containing commercial dolomite filler was measured by Martín et al [48] and found to be about 12.26%. A high-performance SCC (w/C = 0.56, w/b=0.175) comprising 40% dolomite by-product and 2% silica fume as replacement to aggregate exhibited a water penetration of just 15 mm when tested according to EN 12390-8 by measuring the depth of water penetration under pressure [46] although the age of samples when tested was not declared. Rudžionis et al [47] studied the water absorption of SCC mixes incorporating 7-28% of dolomite siftings as partial replacement to sand and found that all mixes had lower water absorption than the control mix but increasing the amount of siftings increased the water absorption and capillary pore average index λ.

The durability of PC-slag, PC-fly ash and PC-slag-fly ash SCC incorporating 30% dolomite powder was assessed by the surface electrical resistivity (SER) using 4-point Wenner probe and found to range between 47.8-54.0 Ω.cm at 28 days, implying low chloride ion permeability [10]. In a recent study, the frost resistance of high-performance SCC was performed by freezing and thawing of partially immersed samples in 3 % NaCl solution. They measured the scaling of the samples and found that after 28 cycles their samples showed good frost resistance with a surface scaling between 150-250 g/m^2 [46]. They believed that surface scaling was caused by the destruction of separate weak dolomite particles. The w/c ration in that study was high at 0.56 and the air content was 2%.

Heirman and Vandewalle [49] studied the freeze-thaw resistance and freeze-thaw and de-icing salt resistance of SCC made with 12 different fillers including 1 dolomite filler. They found that all mixes including the reference mix and dolomite SCC mix exhibited high resistance to freeze-thaw exposure with unappreciable change on the longitudinal elastic modulus (E_{dL}) values as the number of cycles increased. On the other hand, the behaviour after the exposure to freeze-thaw and de-icing salt was different. Similar to Sahmenko et al. [46], the test surface was subjected to a 3% NaCl solution and 28 freezing and thawing cycles. After 7, 14 and 28 cycles, the amount of scaled material related to the test surface is measured, using a trickle of water to catch up the material in a paper filter, which was dried at 105°C afterwards. The authors noticed that the scaled materials of dolomite SCC mix up to 14 cycles were less than the reference vibrated concrete mix and comparable or lower than other SCC mixes. However, after 28 cycles all SCC mixes, except one fly ash SCC mix, had greater amount of scaled material than the reference mix [49]. It can be stated that dolomite SCC has a good freeze-thaw resistance in comparison with the reference concrete and other SCC, but high amount of scaled material is found when de-icing salts were added. Additionally, the results of freeze-thaw and de-icing salt resistance in terms of scaled materials after 28 cycles were 2710 g/m^2 as reported by Heirman and Vandewalle [49], which are much higher than the 150-250 g/m^2 values reported by Sahmenko et al. [46]. These discrepancies can be attributed to the difference in the mix designs of both studies. The dolomite SCC mix studied by Sahmenko et al. [46] is considered high performance SCC as it included silica fume and had higher quantities of dolomite filler than that studied by Heirman and Vandewalle [49]. Thus, it is expected that high performance SCC would perform better than SCC.

The freezing resistance of SCC mixes investigated by Rudžionis et al [47] including dolomite siftings showed better resistance than the control mixes at all levels of replacement. However, increasing the dolomite siftings led to a reduction in the freezing resistance criterion (ks) as a result of the increased and capillary pore average index λ [47]. The authors did not give details on the procedure to measure the freezing resistance. The carbonation depth of SCC mixes incorporating commercial dolomite filler after the exposure to 1% CO_2 (in 65% relative humidity and 20°C) found to be less than 30mm at 28 months of treatment [48]. The behavior of dolomite-based SCC after exposure to high temperatures were examined [57]. They reported that after the exposure to 200 °C, 400 °C and 600 °C the residual strength of the specimens measured was ~80%, ~75% and ~50%, respectively. The study suggested that replacing part of the cement by up to 30% fly ash would be beneficial for high-temperature resistance from compressive strength perspective. Moreover, the residual modulus of elasticity was remarkably influenced by the temperature degree with values of ~82%, 55% and 30% after the exposure to 200 °C, 400 °C and 600 °C, respectively. This indicates that Higher temperatures have more impact on the residual modulus of elasticity compared to the compressive strength.

When reviewing the dolomite effect on concrete properties, it is inevitable to discuss the alkali-carbonate reaction (ACR) or what so called, sometimes, dolomite-alkali reaction. ACR is an unusual and could have a potential deleterious effect on concrete durability although this is still a debatable topic and requires further investigations. The reactions that take place between carbonate rock and Portland cement paste have been investigated by several researchers [59–64]. No data available on the effect of using dolomite powder as a filler in SCC on this phenomenon. It is believed that dedolomitization can take place in certain conditions, which initiate and maintain the dolomite dissolution, leading to the formation of calcite and brucite in the presence of portlandite and forming cracks [65]. Higher temperatures and higher alkalinity content are believed to promote the dedolomitization mechanism [59,60]. However, that mechanism of dedolomitization is still not well understood and the dedolomitization reaction might not be responsible of the deterioration of concretes [61–63]. It is recommended, when using dolomitic aggregate or powder, that a program of testing on alkali-carbonate reaction should be carried out.

6 Conclusion

The intention of this paper has been to review the existing literature on the use of dolomitic filler in SCC in order to enhance the reader's theoretical and practical knowledge and facilitate the further development and application of dolomitic powders in SCC, and the realisation of its many advantages within modern construction technology. Unfortunately, very little research on dolomite effect are available either from field or from laboratory, apart from the reported studies discussed earlier. The available existing literature, however, has reported conflicting conclusions on the properties of SCC made with dolomitic fillers or aggregates. Nevertheless, the use of dolomitic fines would expand our choices when it comes to utilising dolomitic wastes from local quarrying activities. One common element that seems to exist among the studies reviewed that use of dolomitic fines or aggregates can produce good self-compatibility properties of SCC in terms of flowability, passing ability and resistance to segregation. The investigations on mechanical properties of SCC containing dolomitic filler or aggregates suggest that there would be an optimum value of the level of dolomite addition to obtain maximised compressive strength. Durability aspects of SCC incorporating dolomitic fillers or aggregates have been far less investigated and no absolute conclusion can be drawn. Moreover, the alkali-carbonate reaction has not been investigated in any published work for SCC using dolomitic fillers. There are much more to research and investigate to gain a finer understanding of SCC's properties when dolomite sources are incorporating in the mix design as a filler or aggregate.

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