ARTICLE

JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)

مـــــجلــة جــــامعة بـــــــابـل للعلـــــــوم الهندسية

Vol. 32, No. 5. \ 2024

ISSN: 2616 - 9916

A Review of Workability and Mechanical Behavior of Self-Compacting Construction Composites Incorporating Nanomaterials

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Received:	26/11/2024	Accepted:	15/12/2024	Published:	30/12/2024

Abstract

Self-compacting concrete (SCC) is a concrete that can be installed and compacted with or without vibration, without segregation or bleeding, under its weight. Nanotechnology gives materials unique performance, and over the past 20 years, significant efforts have been created to incorporate nanoparticles (NPs) into SCC to enhance functionality and generate SCC with superior characteristics. This improves the proper filling and, consequently, the good structural performance of the restricted areas and the reinforced structural components. With the advantages of SCC in construction engineering, it has become increasingly important in recent years. Nanoparticles are promising substances, and several investigators have employed nanoparticles in SCC to enhance the fresh and hardened microstructure properties. Because of their large surface area, nanomaterials speed up the development of C-S-H gel while improving the pore structure of concrete. The present review paper reviews the impacts of various nanoparticles on the most significant fresh and mechanical characteristics of various SCC composites. As stated by the study's findings, NPs can have a bright future in creating high-performance SCC composites that the construction sector can use effectively because of a notable improvement in workability and mechanical strength.

Keywords: Nanomaterials; SCC composites; Durability; Mechanical strength; Fresh properties

1. Introduction

Conventional concrete's vibration process causes health and safety issues including white finger syndrome, which is extremely difficult for construction workers to deal with, in addition to vibration problems and noise pollution[1]. A new type of concrete called self-compacting concrete is now being produced; it simply expands to fill molds under its weight and without vibration [2]. It was used to ensure proper dictation, good structural performance in locations that are restricted, and heavily reinforced steel structures[3]. This type of concrete has been increasingly used in recent times, partly because of its ease of placing it in areas with heavy reinforcement and hard to reach. In addition, self-compacting concrete has an improved performance in hardening properties such as strength, durability, and surface quality[4]. The production of self-compacting concrete utilizes chemical additives and large quantities of Portland cement, which augments its cost of production as well as the high amount of cement that generates high hydration heat and high autogenous shrinkage[2]. To reduce the cost of self-compacting concrete, metal additives such as nanomaterials were used. In recent years, interest in nanomaterials has increased. When incorporating nanomaterials into concrete, concrete with different properties will be produced. Nanoparticles improve the physical and mechanical properties [2] [6][7].

Research on the addition of various NPs to the SCC is relatively new. The previous 10 years have seen the completion of every study of the incorporation of different NP kinds into SCC composites. Nano silica (NS) in powder or colloidal form, Nano Al2O3 (NA), Nano TiO2 (NT), Nano CuO (NC), NanoFe2O3, Nano Clay (NCl), and Nano CaCO3 (NCa) are the most often utilized NP kinds in SCC composites. Other NP types like Nano ZnO2 (NZ), Carbon nanotubes (CNT), Nano MgO (NM), Nano cement kiln dust (NCKD), and Nano MnFe2O4 (NMF) are also included in SCC composites, although there aren't many studies on the subject [8]. Depending on the kind of nanomaterial, the type of base material (cement paste, mortar, or concrete), and the adjustment's objective, the dose of nanomaterials ranges from 0.5% to 0.12% of the cement weight.[9].

In this paper, a recent review of the effect of the inclusion of different nanoparticles on the fresh and mechanical properties of self-compacting concrete (SCC) is conducted. Therefore, existing and published in the past year studies were conducted to shed light on the various nanoparticles on slump flow diameter, time, box aspect ratio L, funnel flow time V tests, compressive, tensile, and flexural strengths, and modulus of elasticity.

3. Characterization of NPs

3.1. Size and geometry

Even though, strictly speaking, any particle that is less than 100 nm would be considered a nanoparticle (NP)[10], the majority of cement research has been on nanoparticles that are on the size scale of 4–40 nm, with limited exploration of nanoparticles that fall between the range of 40–100 nm[11]. These values indicated the mono-particle diameter, but nanoparticles are generally observed in agglomerates when the particle is 1 mm or larger [12][13]. Nearly all of the nanoparticles are quasi-spherical, and their aspect ratio is rather near to 1. Nano-rutile-TiO2 rods, measuring 10 nm in length and 40 nm in width, have also been explored [14], Additionally, nano-clays, which are shaped like needles or plates, have been investigated. These nano-clays have one or two dimensions on the nano-scale, while the other(s) are on the micro-scale [15][16][17].

3.2. Composition and solid structure

Nano-SiO2 – nano-Al2O3, nano-Fe2O3, nano-TiO2, nano-CaCO3, and nano-clay are the compositional kinds of nanoparticles that have been utilized most often in various cement research projects. Nano-MgO, nano-CaO, nano-Cr2O3, nano-ZnO2, and nano-ZrO2 were some of the compositions that were investigated in a few research[8]. In the majority of instances, nanoparticles (NPs) have been manufactured using the technique of bottom-up chemical synthesis, such as the sol-gel process [18][19]. However, the top-down strategy, which involves milling from the bulk phase, has also been utilized[20]. According to reports, nano-SiO2 has an amorphous solid structure [21]. Only a handful of studies have reported the solid structure of other NPs, such as α-Al2O3[16], γAl2O3 [20], α-Fe2O3[16], γ-Fe2O3[22], anatase-γTiO2 [23], rutile-TiO2 [14], a composite of anatase- and rutile-TiO2 [24], bentonite (i.e., montmorillonite)[17] halloysite [25], palygorskite, and kaolinite[26]. No information is available about the exposed crystal faces of the nanoparticles, which are likely to be their reactive surfaces.

4. Procedure for combining NPs with other SCC components

The nanoparticles possess a diameter of less than 100 nm and exhibit a much larger specific surface area in comparison to fly ash, GGBFS, and silica fume. Thus, they have a low specific gravity in comparison to cement and other powders. Powdered NPs applied separately to the mixer may not be evenly disseminated, leading to agglomeration in the concrete matrix and diminished efficacy. Various scholars advocate colloidal NPs like colloidal NS to solve this problem [6][27][28][29]. Most earlier investigations used powdered NPs due to manufacturing and market availability. Different mixing methods were used in the literature to prevent NP agglomeration. Some researchers dry-combined powdered NP with cement or SCMs before adding it to the pan mixer [30][31]. The prior mixing technique disperses NPs with other SCC constituents without agglomeration. But this method works better when NPs are added at less than 3% of cement weight. The prior mixing operation including nanoparticles and additional components is illustrated schematically in Fig. 1. A modified mixing strategy proposed by Girish et al[32] was later embraced by other researchers[1] [33]. During this process, the NPs were introduced to the mixer in a separate step, along with the other powder ingredients. In addition, a graphic representation of this mixing technique may be shown in Figure 2. NPs were dissolved in water before the addition of additional SCC components, which was another method that was utilized in earlier experiments[27][34].

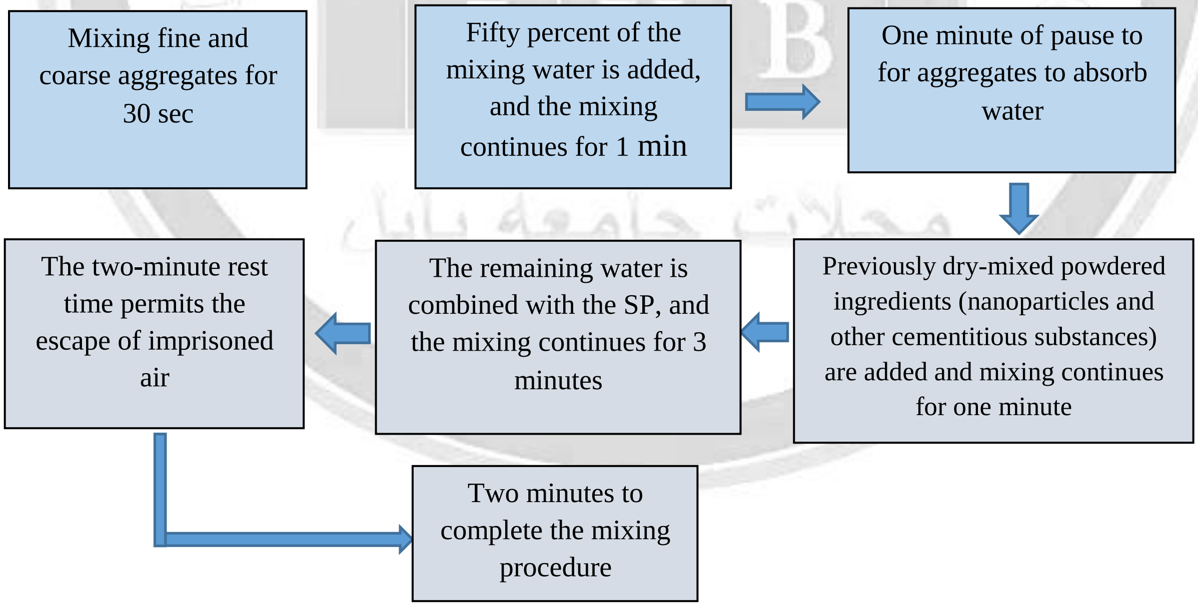

Figure 1. Schematic depiction of the SCC mixing technique using nanoparticles[30][35][31][36]

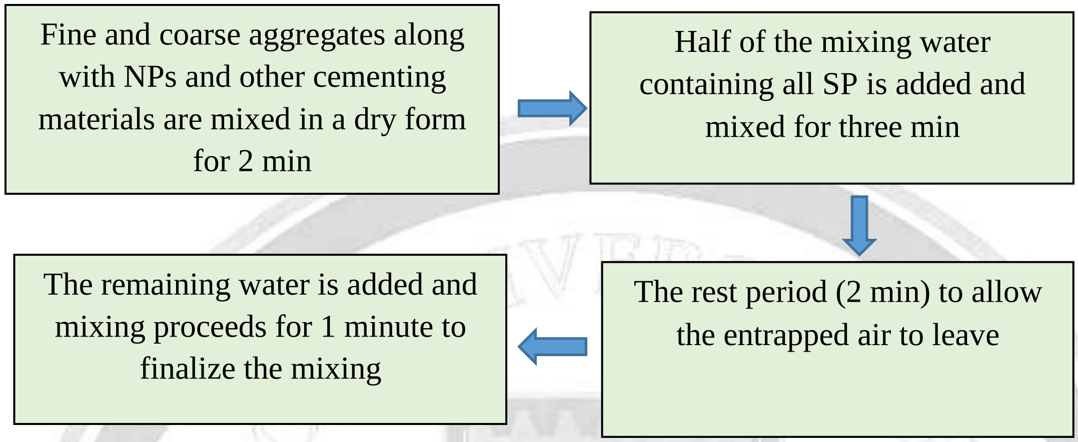

Figure 2: Schematic illustration of the suggested improved mixing process for SCC-incorporated NPs [33][1].

5. Reviewing the fresh and mechanical characteristics of SCC composites modified with NPs

5.1. Fresh characteristics

The researchers determined that many metrics are employed to assess stagnant flow, characterized as free flow and flow devoid of obstructions. The parameters evaluated are the time required for the SCC to create a 500 mm circle, referred to as the flow time (T500), and the stagnation flow diameter (SF). EFNARC, 2005 [37] standard. categorized SF into three classes: SF1 (550-650 mm), SF2 (660-750 mm), and SF3 (760-850 mm). Stagnation flow might range from 550 mm to 850 mm. EFNARC[37]categorized T500 mm diffusion flow into two classifications: VS1 (≤ 2 s) and VS2 (>2 s). The V funnel flow time is categorized into two classes: VF1 (≤ 8 s) and VF2 (9 to 25 s). The minimum requirements for passing the power classes are defined by the L-box ratio as PA1 (≥ 0.80) and the separation resistance of two classes, SR1 (15 to 20) and SR2 (≤ 15).

Hameed et al.[28] investigated the effect of adding colloidal nano-silica (CNS) (2.5%, 5%, 7.5%, and 10%) on the fresh properties of self-compacting concrete containing 10% microsilica. The researchers concluded that the induction of colloidal nano-silica within the mixes caused a decrease in slump flow values from 730 to 677 mm, and an increase in suppression time V from 8.5 to 12 s. However, the L-box data showed just a little difference. Other researchers observed similar results on the influence of NS on self-compacting concrete properties[38][30][35][35][36]. Faez et al.[39] investigated the fresh properties of self-consolidating concrete using Al2O3 NPs as cement replacements at 0, 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, and 3%. The researchers found that most Al2O3 NP combinations slumped less than the control sample. In the collapse flow test, AL2O3 nanoparticles increase concrete component filling, bonding, homogeneity, lower concrete spreading capacity, and decrease concrete spreading diameter. Slump class 2 applies to all concrete combinations. Increased nanoparticle size lowers flowability, yielding, and SCC filling. All V-shaped concrete funnel passage times indicated homogeneous concrete, with no noticeable modification or obstruction during concrete discharge or discharge. The L-box test measures reinforcing bar obstruction and the SCC's ability to pass through tight gaps. All mixtures exhibited blockage ratios ranging from 0.8 to 1.

According to Joshajani et al.[34] , nano-titanium dioxide, nano-aluminum oxide, and nano-iron oxide affect the fresh characteristics of self-consolidating concrete. At 3% and 5% cement weight, titanium dioxide, aluminum oxide, and iron oxide nanoparticles with average sizes of 18, 15, and 14 nm were utilized. The results revealed that adding 3% nanoparticles increased mix workability, but adding 5% diminished it. The droop flow diameter reduced with 5% nanoparticles, while the L-box and V-funnel findings exhibited distinct mixed behavior. According to V-Funnel and L-box, adding 3% nanoparticles to the mixture improved workability, whereas adding 5% diminished it. Jalal et al. [40] examined the characteristics of fresh self-compacting concrete with 0-5 wt% cement substitution with nano titanium dioxide powder. The results indicated that nano titanium dioxide increased the consistency and homogeneity of concrete by reducing fluidity and nano titanium dioxide mixtures showed less bleeding and segregation. Ali et al.[41] examined the fresh characteristics of self-compacting concrete (SCC) with nano-montmorillonite clay (NMMT) at different dosages (0.25, 0.50, 0.75, and 1.00)% by weight of cement. Results indicated that increasing the nano-clay dosage ranging from 0 to 1% reduced the flow diameter to the non-sagging flow class from SCC to SF1. As the nano-clay substitution ratio rose, slump flow and V-shaped funnel test flow times increased. At 1% substitution ratio, V-funnel flow duration (13.33 s) exceeded EFNARC's (2005) maximum accepted limit for SCC (12 s), while the T500 value was below the limit (<5 s) and the blocking ratio of SCC mixes with 1% nano clay was inferior to EFNARC (2005)’s minimum. Ali et al.[42] studied the effect of adding 1%, 2%, and 3% by weight of nano ferrite and manganese cement (Nano-MnFe3O4) on the fresh qualities of self-compacting concrete (SCC) beams. The results demonstrate that all created SCC mixes possess fresh qualities within the permissible parameters for SCC, and the incorporation of N MnFe3O4 enhanced the workability (filling capacity), possibility, and segregation resistance of the SCC. The addition of nano ferrite (1%-3%) gave a SLM value ranging from 650-750 mm, T50 between 3-4 seconds, and pass ability with L-box test between 0.81-0.91. As for the segregation resistance with sieve stability test, the acceptable values are 5.76-7.25%.

Hashim et al. [43]studied the effect of partial replacement of cement with nano metakaolin (NMK) on the freshness and properties of self-compacting concrete (SCHPC), at different ratios (1.25, 2.5, and 3.75). Decreases workability and raises the mixture's viscosity; this impact intensifies as the partial replacement ratio of nano metakaolin to cement weight increases, as the slump ratio and L-box values decrease with increasing the partial replacement ratio of cement with nano metakaolin. While T50 cm² increased with increasing the partial replacement ratio of cement with nano metakaolin.

5.2. Mechanical properties

Nazari and Riahi used SCC as a control mixture and replaced up to 45% of the OPC with ground GGBFS to study the mechanical characteristics of SCC. As a partial replacement of OPC, four different kinds of nanoparticles—SiO2[44], TiO2[45], CuO[46], and Al2O3[47], with the same average particle size and surface area were employed in quantities ranging from 1 to 4%. The findings showed that there were no adverse impacts on the various mixes' mechanical characteristics. Generally speaking, the combinations with 3% nanoparticles exhibit the greatest strength improvement. When comparing the outcomes of the combinations that performed better, we find that adding Al2O3 increases compressive strength the most, by almost 57%, followed by SiO2, CuO, and TiO2. Adding nano-silica (+43%) resulted in the largest improvement in flexural strength, followed by Al2O3 (+31%) and CuO and TiO2 (~+30%). The split tensile strength of mixtures including Al2O3 or CuO increases by almost 52%, whereas SiO2 and TiO2 SCC mixes rise by roughly 48% and 33%, respectively. Hamed et al.[28] examined the effects of nano-silica (CNS) at four replacement ratios (2.5%, 5%, 7.5%, and 10%) on self-compacting concrete's compressive, tensile, and elastic modulus. Compared to the reference sample, concrete prepared from cement replacements at 2.5%, 5%, 7.5%, and 10% CNS increased compressive strength by 29.32%, 40.82%, 45.8%, and 48.1% and tensile strength by 16.67% to 34.87%. At 2.5% nano-silica, the elastic modulus was best.

Wang et al.[5] conducted a thorough investigation of how silicon dioxide nanoparticles with an average diameter of around 20 nm may alter cementitious materials. To determine how silicon dioxide nanoparticles affected the mechanical qualities, cement paste was mixed with 1%, 3%, and 5% of silicon dioxide nanoparticles. The results demonstrated that adding 3% silicon dioxide nanoparticles to cementitious materials increased their mechanical characteristics, and the test pieces' early strength improvement was evident. There was an 18.5% rise in the 28-day compressive strength and a 33.2% increase in the 3-day one.

Mohseni et al.[48] investigated the singular and synergistic impacts of nano-silicon dioxide (NS), nano-aluminum oxide (NA), and nano-titanium dioxide (NT) on the mechanical characteristics of self-compacting mortar (SCM) using fly ash. Three distinct nanoparticles were utilized at 1%, 3%, and 5% binder by weight, whilst maintaining a constant fly ash content of 25% relative to the cement weight throughout all mixes. The findings demonstrated that 1%, 3%, and 5% binder yielded optimal compressive strength for NA, NS, and NT nanoparticles, respectively, when utilized independently. For all formulations, the strength augmented and attained its peak by the 90th day. The use of NS powders markedly enhanced compressive strength in the first phases relative to other nanoparticle additions. Nonetheless, after 28 and 90 days, no significant difference was seen among the mortars containing various nanoparticles. Of all the samples, the 5%NS samples exhibited the greatest compressive strength, closely followed by the 5%NT samples.

The impact of adding 0.5%, 2%, and 4% nano-SiO2, TiO2, and Al2O3 on the mechanical characteristics of self-compacting concrete was examined by Nevedomskiy et al. [49]According to the findings, the compressive and flexural strengths at 28 days were improved by adding up to 4 % nano-SiO2. Conversely, no improvement in concrete containing nano-TiO2 and nano-Al2O3. At 90 days, the flexural strengths of all nano-modified concretes were lower than those of the reference concrete, and the elastic modulus values of concrete samples aged for 90 days were greater when nano-admixtures were used. The impact of adding 0.25, 0.5%, and 0.75% nano-silica on the mechanical characteristics of self-consolidating concrete at three distinct weight/weight ratios (w/b) of 0.41, 0.45, and 0.5 was investigated by Hani et al [50]. The findings demonstrated that a certain dosage of nano silica had a higher impact on high w/b concrete's compressive strength than low w/b concrete. In terms of durability, the findings demonstrated that low w/b mixes were more affected by a specific dosage of micro silica than high w/b mixes. Adding nano-silica to all mixtures improved the compressive and tensile strengths. The reduction in compressive strength can be made up for by adding nano-silica.

The impact of adding iron oxide nanoparticles at 1%, 2%, 3%, 4%, and 5% on the compressive, tensile, and splitting strengths of high-performance self-compacting concrete was investigated by Khoshakhlagh et al.[51] The researchers found that the compressive, tensile, splitting, and flexural strengths of self-compacting concrete specimens rose when the iron oxide nanoparticle concentration was raised to 4 weight percent. However, specimens with 5.0 weight percent iron oxide nanoparticles had substantially greater compressive, splitting tensile, and flexural strengths than the control specimen.

Magnesium oxide (MgO) nanoparticles' impact on the mechanical characteristics of self-compacting concrete was studied by Fard and Jabbar [52]Various weight ratios of cement and magnesium oxide nanoparticles were used to create self-compacting concrete: 1, 2, 3, and 4. The results demonstrated that the ideal quantity of usage for self-compacting concrete was 2% by weight of cement, which enhanced the concrete's tensile, flexural, and compressive strengths by 33%, 20%, and 59%, respectively, at 28 days of age.

Zuhair and Habeeb et al. [53] examined the mechanical characteristics of self-compacting concrete (SCC) with 0, 1, 3, and 5% nano metakaolin (NMK) as a partial weight replacement of cement. This study indicated that SCC mixes with 5% nano metakaolin as a partial weight replacement of cement had the greatest mechanical characteristics. NMK). At ages (3, 7, 28, 56) days, the mixture containing 1%NMK, 3%NMK, and 5%NMK has a compressive strength of (46, 41, 33) %, (83, 51, 30) %, (42, 29, 12) %, and (50, 34, 16) % greater than typical concrete mixes (PC). Self-compacting concrete containing (1, 3, 5) % nano-metakaolin had a higher flexural strength at ages (28, 56, 90) days than (PC) mixtures by about (14,5, 26, 34) %, (20, 14, 50) %, and (16, 37, 46) %, respectively.

6. Conclusions

This article examines the workability and mechanical characteristics of self-compacting concrete (SCC) including nanomaterials. The subsequent conclusions may be derived from the findings of this review:

1 -Previous studies indicate that nanoparticles' large specific surface area, compared to cement and other complementary cementitious materials, significantly enhances the viscosity and cohesion of SCCs when incorporated. Moreover, nanoparticles absorb large amounts of water from the mixture due to their small size and large surface area, which leads to a decrease in the workability of newly mixed SCCs. As a result, the fluidity and workability properties of SCCs modified with nanoparticles are reduced.

2 -The mechanical performance of SCCs, using different types of nanoparticles, is significantly improved.

3 -Nano-silica is a superior nanomaterial as SCCs modified with nano-silica have shown superior performance compared to other nano-modified SCCs.

4 -The high cost of nanoparticles poses a major challenge in extending the long service life of self-consolidating concrete modified with these materials in the future. The application of nanomaterials to improve the performance of self-consolidating concrete remains the goal in this field.

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ARTICLE
JOURNAL`S UNIVERSITY OF BABYLON FOR ENGINEERING SCIENCES (JUBES)
مـــجلــة جـــامعة بـــــابــل للعلـــــوم الهندسية
Vol. 32, No. 5. \ 2024
ISSN: 2616 - 9916

مقال مراجعة عن قابلية التشغيل والسلوك الميكانيكي للمركبات الإنشائية ذاتية الضغط التي تحتوي على مواد نانوية

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الخلاصة

الخرسانة ذاتية الدمج هي خرسانة يمكن تركيبها وضغطها مع أو بدون اهتزاز، بدون فصل أو نزيف، تحت تأثير وزنها. تمنح تقنية النانو المواد أداءً فريدًا، وعلى مدار العشرين عامًا الماضية، بُذلت جهود كبيرة لدمج الجسيمات النانوية في الخرسانة ذاتية الدمج لتحسين الأداء وإنتاج الخرسانة ذاتية الدمج بميزات أفضل. وهذا يعزز الملء المناسب، وبالتالي الأداء الهيكلي الجيد للمناطق المقيدة والمكونات الهيكلية المقواة. مع مزايا الخرسانة ذاتية الدمج في مجال هندسة البناء، أصبحت مهمة بشكل متزايد في السنوات الأخيرة. الجسيمات النانوية هي مواد واعدة، وقد استخدم العديد من الباحثين الجسيمات النانوية في الخرسانة ذاتية الدمج، بهدف تعزيز خصائص الطازجة والمصلبة. نظرًا لمساحتها السطحية الكبيرة، تعمل المواد النانوية على تسريع تطوير هلام C–S–H مع تحسين بنية مسام الخرسانة. تستعرض ورقة المراجعة الحالية تأثيرات الجسيمات النانوية المختلفة على أهم الخصائص الطازجة والميكانيكية لمختلف مركبات الخرسانة ذاتية الدمج. وفقًا لنتائج الدراسة، فإن إدراج الجسيمات النانوية يمكن أن يكون له مستقبل مشرق في إنشاء مركبات SCC عالية الأداء والتي يمكن لقطاع البناء استخدامها بشكل فعال بسبب التحسن الملحوظ في قابلية التشغيل والمقاومة الميكانيكية.

الكلمات الدالة:– المواد النانوية، مركبات SCC، المتانة، المقاومة الميكانيكية، الخواص الطازجة.