Journal of AL-Rafidain University College for Sciences (2022); Issue 52; 227 -236

AL- Rafidain University College

PISSN: (1681-6870); EISSN: (2790-2293)

Journal of AL-Rafidain University College for Sciences

Available online at: https://www.jrucs.iq

JRUCS

Journal of AL-Rafidain University College for Sciences

Study of the Behavior of Self-Sensing Concrete under the Influence of Different Mechanical Loads: A Review

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Article Information

Article History:
Received: September, 26, 2022
Accepted: October, 26, 2022
Available Online: December, 31, 2022

Keywords:
Compressive strength, flexural strength, self-sensing concrete, tension strength.

Abstract

Self-sensing concrete is an intelligent application of scientific knowledge for practical purposes and new concrete structures, which can feel the damage, stress and strain in the body of concrete. It has been widely used because of its possibility of getting efficient cost solution for controlling the structural sustainability of concrete structures, which indicate, that it is very impressive during the design life of the facilities. This review contains universal behavior and global information about different conditions of loading for self-sensing concrete. Also, the definitions and applications of intrinsic and non-intrinsic self-sensing concretes are mentioned. Moreover, a major confirmation is stated on the application of scientific knowledge for practical purposes and new concrete structures. The characteristics of self-sensing concrete provide an ability to reveal small cracks before they begin to become significant. During unchanging compression, firstly, the values of electrical resistivity decrease through an increase in load, subsequently become stable and then increased suddenly. While, during impact loading, the electrical resistivity decreases suddenly, but it regresses then to 0 after loading. However under tensile stress, the electrical resistivity increases as the tensile stress increases. Nevertheless, since the flexural is a component of compression and tension, the comparison between sensitivity for compression part is much smaller than in tension part.

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doi: https://doi.org/10.55562/jrucs.v52i1.555

1. Introduction

Since the concrete has been vastly wide utilize (which about 30 million tons every year). But it still there are weaknesses points inside concrete which are unavoidable effects of long-term mechanical and environmental influences such as scaling, deformation, deterioration and cracking (1, 2).

Self-sensing concrete (SSC) which it is also known as piezoresistive or self-monitoring or pressure-sensitive or smart intrinsically concrete as shown in Figure 1(1, 2).

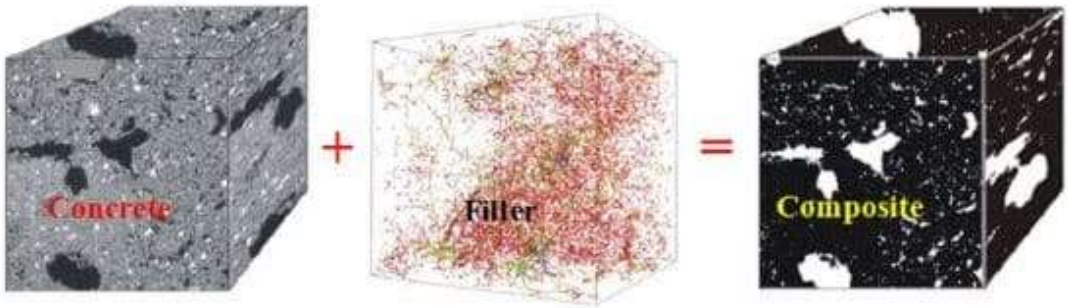

Figure 1: Structure of Self-Sensing Concrete.

The technology of structural health monitoring (SHM) supplies the capacity for controlling the situation to include infrastructures safety throughout usage age of the structure. For the reason of monitoring and evaluation, sensors are fundamentally applied such as gauges of electric resistivity strain, visual sensors and sensors of piezoelectric strain: although, uses of these sensors have some responses like low sensitivity and low durability. A novel evolution of intelligent construction materials inclusive cement-based sensors could be fix those matters (3).

The intrinsic self-sensing concrete (ISSC) contains different types of filling materials such as graphite powder (GP), carbon nanomaterials, carbon black (CB), carbon fibers (CF) and other types to conventional concrete, so supplying the capability to control failure and stress to strain and enhancing mechanical characteristics (4). Many articles investigates were stated so as to check the behavior of SSC, which includes its application for monitoring the traffic (5), monitoring the corrosion (6), sensing the strain (7), monitoring the seismic damage (8). Moreover, many articles investigates were clarified to define the characteristics of SSC contains of various useful filling materials such as carbon fibers (9), carbon nanofibers (10), carbon nanotubes (11–13), graphene nanoplatelets (14), steel fibers (15), and glass fibers (16) . After all, the characteristics of SSC are affected by initial situations and a lot of factors such as particularly the matrix material, material selection, further dispersion processes, functional filler and dispersion material. A remarkable phase in the elaboration steps is the design of the mix, which consists of the chosen of the best concentration of useful fillers which varies depending on the material type. Subsequently, the mix design of self-sensing concrete is various and greatly depend on filler characteristics. Likewise, materials and methods used to control the capabilities of concrete sensing vary and are fundamentally elected according to the predilections of authors. Many papers regarding to the uses of self-sensing concrete and the latest founding differ depending on the situations of loading and also depending on many factors influencing the electrical resistivity of it (17).

2. Literature review

The affinity between external force and alteration in electrical resistivity could distinguish the behavior of sensing for concrete. Moreover, force sensitivity coefficients, the coefficients of stress sensitivity and amplitude of variation in electrical resistance are another factors which can characterize such a significant variable as concrete sensitivity. In general, and at different loading types, like, flexural, tension and compression, the major idea of self-sensing concrete is that the concrete can explain various sensing attitudes and also concrete can be influenced by large number of objects which has an effect on electrical resistance of the matrix.

2.1 Behavior under Compression

At different loading types, various attitude of self-sensing concrete can be seen (18). When the load increases during monotonic compression, the amounts of the electrical resistivity Dr/ro at first decreases then turn out to be stable and eventually an expected increase takes place, as shown in Figure 2. The succession of situations is clarified by the induction of fresh cracks, compression pressure and cracks expansion (19). At first, under uniaxial pressure, the area of the conductive particles decreases, which leads to the improvement of the conducting connection network into the concrete structures. After that, demolition is observed in addition to the rebuilding of this network during the growth of new cracks. At last, extension of cracks leads to disturbance of the conducting connection network into the concrete structures (20).

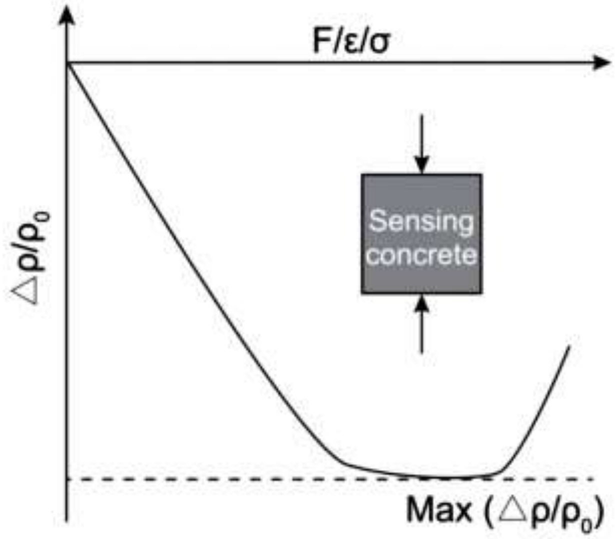

Figure 2: Self-sensing concrete under monotonic compression (20).

Through the loading phase, while the specimen is liable to frequent pressure, the electrical resistivity Dr/ro decreases and then it increases again during the unloading phase. At any way, at the start of all load period is variable in proportion from the resistivity at the beginning state of samples, which was not under compressing stress (21). During the compaction of compression, the cracks or internal voids are minimized and this explained the different values of electrical resistance. However, first reading for the electrical resistivity is unlike to the baseline of the already loaded compound, and the stress came back to zero. Also, the difference of the Dr/ro can be demonstrated by the final strength of self-sensing concrete. By frequent compression, if the sample is subjected to a compression capacitance equal to 30-75% of the final force, the base resistance will be non-reversible and the variation in electrical resistance will be reversible, while when the capacitance is reduced to less than 30%, the baseline will be with a reversible variation in electrical resistance (4). Getting rid of both baseline and variation in electrical resistance is irreversible in pressure stress capacity above 75% because of demolition of conductive network.

One of the most usual loads that structures made with concrete are exposed to is impact load. Through the stage of impact load, Dr/ro has become decreases suddenly; but then comes back to zero after the loading stage, that which can be seen in Figure 3. The change in electrical resistance increases as the capacity of the impact load increases, that’s because the electrical resistivity of a specimen is rely on the capacity or amplitude (21). Meehan et al. stated (22), the large number of impacts or increase value of impact load capacity can effect in the situation where electrical resistance will not recuperate and come back to zero because of the damage inflicted inside self-sensing concrete (4).

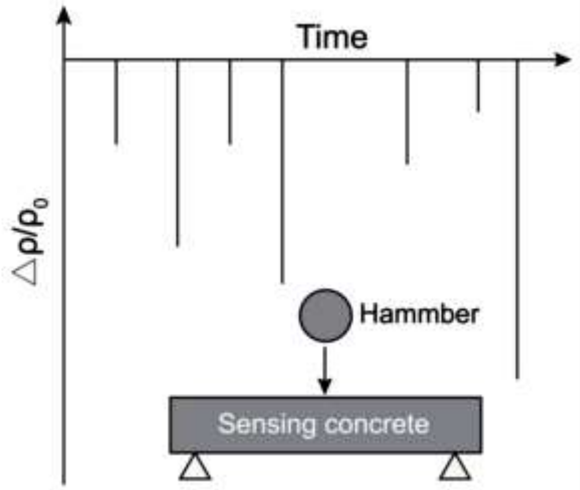

Figure 3: Self-sensing concrete under impact load (20).

2.2 Behavior under Tension

As tensile stress increases, the electrical resistivity Dr/ro increases; during the monotonic tension, when the fillers that are inner the concrete disconnect, the micro-cracks are generated (Figure 4). Nevertheless, the partial variation in electrical resistance begins to increase faster after the tensile strain eventually due to the structure deterioration (22). Thus, the concrete sensing counts on the cracking attitude inside of the specimen not only on the tensile strain (20). Reza et al. (23) discussed the self-sensing attitude of the concrete with carbon fiber under concentrated tension. Many studies discovered that the electrical resistance can be utilized to watch the techniques of the failure zone and help to compute transmitting the length of crack.

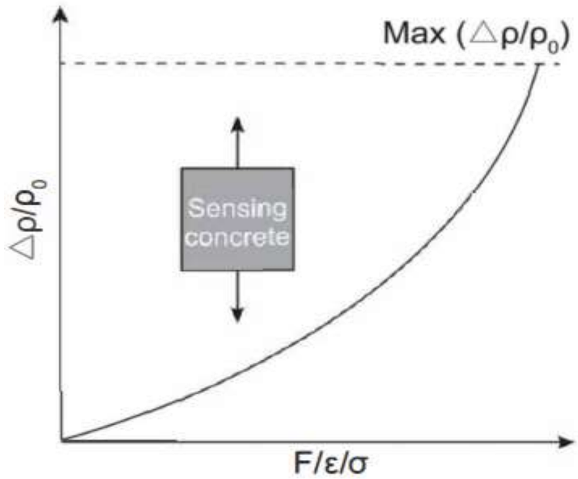

Fig. 4 Self-sensing concrete under monotonic tension (20).

While the repeated tension is undergoes to a specimen, the electrical resistivity decreases with unloading stage and increases with loading stage. The change situation in Dr/ro is alike to the loading under regenerated compression stress where the electrical resistivity and the baseline are changed at various rates of capacitance. Specially, in the elastic area, the electrical resistivity and the baseline variations are reflectable, but both of them is irreflectable when the elastic distortion area is exceeded by the load capacitance (4).

2.3 Behavior under Flexure

Compression stage and tension stage are fractions of self-sensing concrete which act in adverse method (4), as shown in Figure 5, the beam is loaded at the center and in the deflection part of concrete specimen, the sensitiveness of compression part is less than the tension part that can be demonstrated by the rise in concrete compressive strength of concrete unlike in the concrete tensile strength (7).

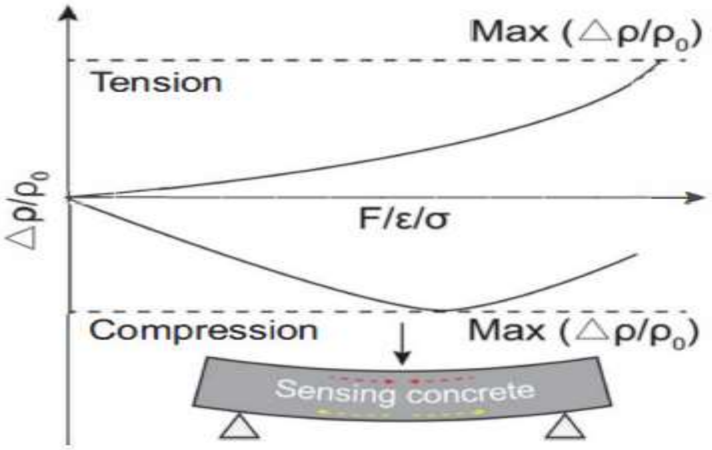

Figure 5: Self-sensing concrete under flexure (20).

Wang et al. (24), stated that as load increases, at the ultimate flexural strength the electrical resistivity got to the minimum point, after that unexpected rise in electrical resistivity was seen after increasing loading. Besides, paper made by Azhari and Banthia (25) concluded that in a specimen with 5% by volume of carbon fiber, first of all, the electrical resistivity minimized unexpectedly with the rise in the perpendicular displacement of the concrete. Yet, the electrical resistivity began to rise when the displacement about 0.3 mm and rises with load till the fracture happening. At displacement become 0.35 mm, the resistivity stopped after reduction of step by step. In different studies made by Chen and Liu (27), the authors matched the variation in electrical resistivity of specimens made with 0.22, 0.55 and 0.80% volume of carbon fiber. The author concluded that, the sample with 0.55% volume of carbon fiber, the increase in loading lead to electrical resistivity decreased; however, opposite findings were gained for specimens made with 0.22 and 0.80% volume of carbon fiber, which increasing the load lead to increase the resistivity.

3. Applications of SSC

There are two type of SSC, intrinsic self-sensing concrete (ISSC) which known also as intrinsically smart, intrinsic SSC which is define as invented by the addition of conductive incorporations, such as carbon or steel particles to the mix, which provides the concrete the capability to work as a self-sensing complex with no necessity to other outer sensors. While non-intrinsic self-sensing concrete (NISSC) which define as the concrete that contains sensors to measure strain gauges and other sensors, for example piezoceramic transducers, lead zirconate titanate-based piezoelectric sensors and elective fiber sensors (27-31), are to be prepared and included inside concrete structures. However these non-intrinsic trade sensors are uncomplicated to install, having good repeatability and low in cost (32).

3.1.Applications of ISSC

A- Structural Health Monitoring (SHM)

The non-intrinsic self-sensing concrete (NISSC) can be utilized in bonded, mass, , sandwich, embedded and coating forms for structural health monitoring, see Figure 6 (4).

B- Traffic Detection

The bridge or pavement sections incorporated with the non-intrinsic self-sensing concrete non-intrinsic self-sensing concrete, see Figure 7, can expose many of significant traffic information such as vehicular speed, traffic flowing rates, weighing in motion and also the traffic density (4).

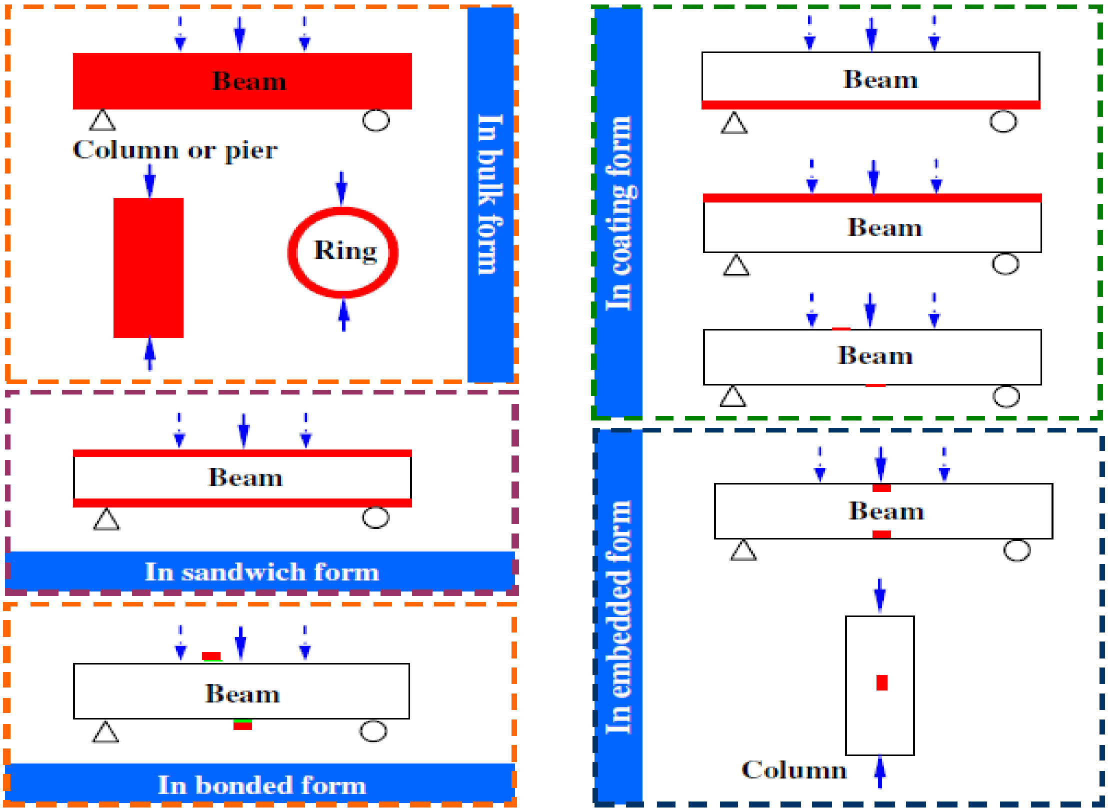

Figure 6: Applications of ISSC in beams (4)

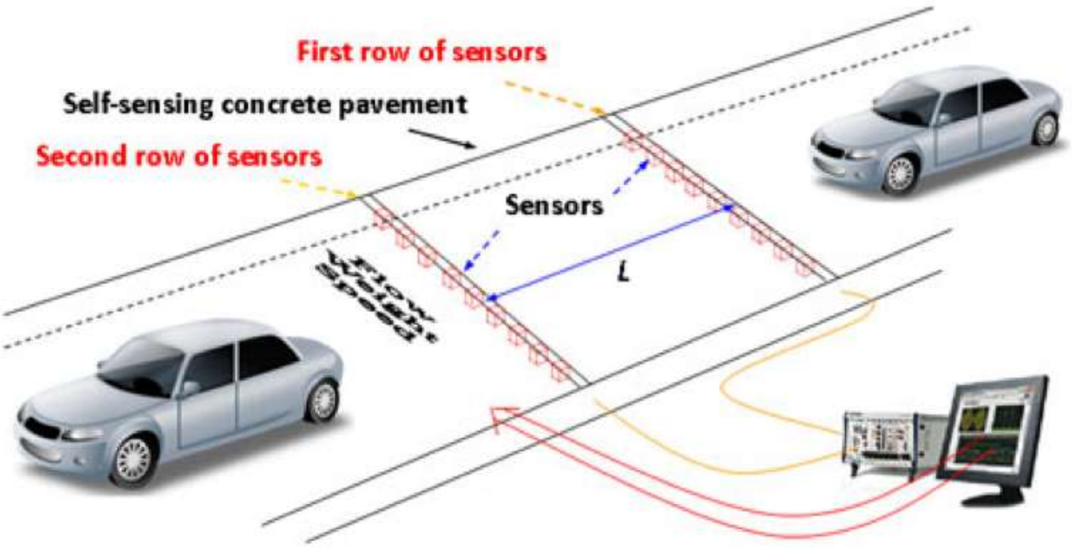

Figure 7: Application of ISSC in bridges (4)

3.2.Applications of NISSC

A-NISSC incorporated with elective fibers

Elective fibers can be integrated inside concrete for calculating the displacement, strain, corrosion, moisture content, temperature and crack through determining the variation in phase, intensity, the time of light transited into fibers or wavelength and polarization (32).

B- NISSC incorporated with piezoelectric materials

Piezoelectric materials (PM) show the sensing capability resulting from piezoelectric impact; whereas the charge on the surface is formed as a reaction of a direct effect applied (mechanical stresses), and on the contrary, a mechanical strain is manufactured in reply to a converse effect (the electric field applied) (32).

C- NISSC integrated with shape memory alloys

The electrical resistance of shape memory alloys (SMA) is raised with the applying of tension strain. To control the crack width estimation besides the deformation or strain of concrete shape memory alloys can be used (32).

D- NISSC incorporated in self-monitoring polymers composite

The polymer template or polymer matrix consists of conductive powder and electric conductive phase. The polymer matrix is the main component of self- monitoring or self- diagnosing polymer composites (SDPC). The uniform alteration in electrical resistivity of self-monitoring polymers matrices happens because of the external force, thus they have the can measure electrical resistance which could have the capabilities in controlling deformation or strain, damage of concrete and crack (32) .

4. Conclusions

From the review in this research, the following conclusions can be adopted:-

- Characteristics of SSC supply a capability to reveal a small crack prior to become a series of cracks, which is fatal in various civil infrastructures repair such as bridges, dams, so tall buildings, nuclear power plants, highways and pipelines.
- As for the compressive resistance, it has been observed that the electrical resistivity begins to decrease when the loads increase, then reaches the break-even point, and then begins to rise.
- While for the impact strength, the electrical resistivity decreases with increasing impact loading and then begins to rise until it reaches zero and stopped there.
- As tensile stress increases the electrical resistivity increases.
- Since the flexural strength consist of compression and tensile stress, so when flexural loading the sensitivity of compression part is less than the tension part leading to increases in electrical resistivity.

References

[1] Konkanov, M.; Salem, T.; Jiao, P.; Niyazbekova, R.; Lajnef, N. Environment-Friendly, Self-Sensing Concrete Blended with Byproduct Wastes. Sensors 2020, 20, 1925. [CrossRef]

[2] Dong, W.; Li, W.; Tao, Z.; Wang, K. Piezoresistive properties of cement-based sensors: Review and perspective. Constr. Build. Mater. 2019, 203, 146–163. [CrossRef]

[3] Ou, J.; Han, B. Piezoresistive Cement-based Strain Sensors and Self-sensing Concrete Components. J. Intell. Mater. Syst. Struct. 2009, 20, 329–336. [CrossRef]

[4] Han, B.; Ding, S.; Yu, X. Intrinsic self-sensing concrete and structures: A review. Measurement 2015, 59, 110–128. [CrossRef]

[5] Han, B.; Zhang, K.; Burnham, T.; Kwon, E.; Yu, X. Integration and road tests of a self-sensing CNT concrete pavement system for traffic detection. Smart Mater. Struct. 2013, 22, 015020. [CrossRef]

[6] Lu, Y.; Zhang, J.; Li, Z.; Dong, B. Corrosion monitoring of reinforced concrete beam using embedded cement-based piezoelectric sensor. Mag. Concr. Res. 2013, 65, 1265–1276. [CrossRef]

[7] Wen, S.; Chung, D. Carbon fiber-reinforced cement as a strain-sensing coating. Cem. Concr. Res. 2001, 31, 665–667. [CrossRef]

[8] Downey, A.; D'Alessandro, A.; Laflamme, S.; Ubertini, F. Smart bricks for strain sensing and crack detection in masonry structures. Smart Mater. Struct. 2017, 27, 015009. [CrossRef]

[9] Sassani, A.; Arabzadeh, A.; Ceylan, H.; Kim, S.; Sadati, S.S.; Gopalakrishnan, K.; Taylor, P.C.; Abdualla, H. Carbon fiber-based electrically conductive concrete for salt-free deicing of pavements. J. Clean. Prod. 2018, 203, 799–809. [CrossRef]

[10] Galao, O.; Baeza, F.J.; Zornoza, E.; Garcés, P. Strain and damage sensing properties on multifunctional cement composites with CNF admixture. Cem. Concr. Compos. 2013, 46, 90–98. [CrossRef]

[11] Han, B.; Yu, X.; Kwon, E. A self-sensing carbon nanotube/cement composite for traffic monitoring. Nanotechnology 2009, 20, 445501. [CrossRef]

[12] Spinelli, G.; Lamberti, P.; Tucci, V.; Guadagno, L.; Vertuccio, L. Damage Monitoring of Structural Resins Loaded with Carbon Fillers: Experimental and Theoretical Study. Nanomaterials 2020, 10, 434. [CrossRef]

[13] Murray, C.M.; Doshi, S.M.; Sung, D.H.; Thostenson, E.T. Hierarchical Composites with Electrophoretically Deposited Carbon Nanotubes for In Situ Sensing of Deformation and Damage. Nanomaterials 2020, 10, 1262. [CrossRef]

[14] D'Alessandro, A.; Ubertini, F.; Downey, A.; Laflamme, S.; Meoni, A. Strain monitoring in masonry structures using smart bricks. In Proceedings of the Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2018; Sohn, H., Ed.; SPIE: Bellingham, WA, USA, 2018; p. 66. [CrossRef]

[15] Sun, M.-Q.; Liew, R.; Zhang, M.-H.; Li,W. Development of cement-based strain sensor for health monitoring of ultra high strength concrete. Constr. Build. Mater. 2014, 65, 630–637. [CrossRef]

[16] Goldfeld, Y.; Rabinovitch, O.; Fishbain, B.; Quadflieg, T.; Gries, T. Sensory carbon fiber based textile-reinforced concrete for smart structures. J. Intell. Mater. Syst. Struct. 2015, 27, 469–489. [CrossRef]

[17] Abdullah, W.; Mohammed, A.; Abdullah, A. Self-Sensing Concrete: A Brief Review. Int. J. Adv. Mech. Civil Eng. 2019, 6, 2394–2827.

[18] Mishnaevsky, L.; Dai, G. Hybrid carbon/glass fiber composites: Micromechanical analysis of structure–damage resistance relationships. Comput. Mater. Sci. 2013, 81, 630–640. [CrossRef]

[19] Uri, D.; Ackermann, K.C. Self-Sensing Concrete for Structural Health Monitoring of Smart Infrastructures. Master's Thesis, University of Rhode Island, Kingston, RI, USA, 2018. Paper 1285.

[20] Ding, S.; Dong, S.; Ashour, A.; Han, B. Development of sensing concrete: Principles, properties and its applications. J. Appl. Phys. 2019, 126, 241101. [CrossRef]

[21] Han, B.; Yu, X.; Ou, J. Sensing Properties of Self-Sensing Concrete. Self-Sensing Concrete in Smart Structures; Elsevier: Amsterdam, the Netherlands, 2014; pp. 95–162. [CrossRef]

[22] Meehan, D.G.; Wang, S.; Chung, D. Electrical-resistance-based Sensing of Impact Damage in Carbon Fiber Reinforced Cement based Materials. J. Intell. Mater. Syst. Struct. 2009, 21, 83–105. [CrossRef]

[23] Reza, F.; A Yamamuro, J.; Batson, G.B. Electrical resistance change in compact tension specimens of carbon fiber cement composites. Cem. Concr. Compos. 2004, 26, 873–881. [CrossRef]

[24] Wang, X.; Wang, Y.; Jin, Z. Electrical conductivity characterization and variation of carbon fiber reinforced cement composite. J. Mater. Sci. 2002, 37, 223–227. [CrossRef]

[25] Azhari, F.; Banthia, N. Cement-based sensors with carbon fibers and carbon nanotubes for piezoresistive sensing. Cem. Concr. Compos. 2012, 34, 866–873. [CrossRef]

[26] Chen, B.; Liu, J. Damage in carbon fiber-reinforced concrete, monitored by both electrical resistance measurement and acoustic emission analysis. Constr. Build. Mater. 2008, 22, 2196–2201. [CrossRef]

[27] Li G.Y. Pressure-sensitive properties and microstructure of carbon nanotube reinforced cement composites. Cement Concr Compos. 2007.

[28] Zhao J. Smart aggregate-piezoceramic patch combination for health monitoring of concrete structures. Journal of Sensors.2016.

[29] Yoo D. Self-sensing capability of ultra-high-performance concrete containing steel fibers and carbon nanotubes under tension. Sens Actuators A Phys. 2018.

[30] Chung D.D.L. Cement reinforced with short carbon fibers: a multifunctional material. Compos B Eng. 2000.

[31] Sun M. A study of piezoelectric properties of carbon fiber reinforced concrete and plain cement paste during dynamic loading. Cement Concr Res. 2000.

[32] Han B., Zhang L., and Ou J. Smart and multifunctional concrete toward sustainable infrastructures, Springer 2017.

مجلة كلية الرافدين الجامعة للعلوم (2022)؛ العدد 52؛ 227 -236

AL- Rafidain University College

PISSN: (1681-6870); EISSN: (2790-2293)

مجلة كلية الرافدين الجامعة للعلوم

Available online at: https://www.jrucs.iq

JRUCS
Journal of AL-Rafidain University College for Sciences

دراسة سلوك الخرسانة ذاتية الاستشعار تحت تأثير الأحمال الميكانيكية المختلفة: مراجعة

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المستخلص

الخرسانة ذاتية الاستشعار هي تطبيق ذكي للمعرفة العلمية لأغراض عملية وهياكل خرسانية جديدة يمكن أن تشعر بالضرر والاجهاد والانفعال في جسم الخرسانة، والتي تم استخدامها على نطاق واسع بسبب إمكانية الحصول على افضل الحلول الاقتصادية للتحكم بالاستدامة الهيكلية للمنشآت الخرسانية، مما يدل على أنها رائعة للغاية اثناء العمر التصميمي للمنشآت. تحتوي هذه المراجعة على سلوك عالمي ومعلومات عالمية حول الظروف المختلفة لتحميل الخرسانة ذاتية الاستشعار. أيضا، تم ذكر تعريفات وتطبيقات خرسانة الاستشعار الذاتي الجوهرية وغير الجوهرية. علاوة على ذلك، هناك تأكيد رئيسي على تطبيق المعرفة العلمية للأغراض العملية والهياكل الخرسانية الجديدة. توفر خصائص الخرسانة ذاتية الاستشعار القدرة على الكشف عن الشقوق الصغيرة قبل أن تبدأ في أن تصبح مهمة. أثناء الضغط غير المتغير، أولاً، تنخفض قيم المقاومة الكهربائية من خلال زيادة الحمل، ثم تصبح مستقرة ثم تزداد فجأة. بينما، أثناء تحميل الصدمات، تقل المقاومة الكهربائية فجأة ولكنها تتراجع بعد ذلك إلى 0 بعد التحميل. ولكن تحت إجهاد الشد، تزداد المقاومة الكهربائية مع زيادة إجهاد الشد. ومع ذلك، نظرًا لأن الانحناء هو أحد مكونات الضغط والشد، فإن المقارنة بين الحساسية لجزء الضغط تكون أصغر بكثير منها في جزء الشد.

معلومات البحث

تواريخ البحث:
تاريخ تقديم البحث: 2022/9/26
تاريخ قبول البحث: 2022/10/26
تاريخ رفع البحث على الموقع: 2022/12/31

الكلمات المفتاحية:
مقاومة الانضغاط، مقاومة الانثناء، الخرسانة ذاتية الاستشعار، مقاومة الشد.

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doi: https://doi.org/10.55562/jrucs.v52i1.555