Mechanical Behavior of Self-Compacting Concrete Containing Nano-Metakaolin

Mohammed Kareem Abed
Technical Institute-Babylon
Mohammed_k1965@yahoo.com

Zuhair Dhaher Habeeb
Technical Institute-Babylon
en_zoher@yahoo.com

Abstract

This paper presents the influence of nano- metakaolin addition for production self-compacting concrete (SCC). Nano-metakaolin material was used at four percentages (0, 1, 3 and 5) % as partial replacement by weight of cement [Reference mix (PC), (1%, 3%, 5% nano-metakaolin)(1, 3, 5 NMK)]. This research studied the influence of nano-metakaolin material on the fresh and mechanical properties which represented by the different tests were slump flow, T_{50cm}, L-Box, V-funnel, compressive and flexural strength. From the results of this study, found that the SCC with 5% of nano-metakaolin material as partial replacement by weight of cement give the best results of fresh and mechanical properties of SCC mixes.

Key words: Nano-metakaolin, Self-compacting concrete, Fresh and mechanical properties

الخلاصة

يبين هذا البحث دراسة تأثير اضافة مادة النانوميتاكاؤولين للخرسانة الذاتية الرص. استخدمت مادة النانوميتاكاؤولين بأربعة نسب هي (0، 1، 3، 5) % كتعويض جزئي من وزن الاسمنت [(المرجعية (PC) و(5,3,1)% نانو ميتاكاؤولين (1,3,5 NMK)]. تم في هذا البحث دراسة تأثير مادة النانوميتاكاؤولين على الخواص الطرية والميكانيكية والتي تمثلت بعدة فحوصات هي الانسياب، T_{50cm} ، الصندوق على شكل L، القمع على شكل V، ومقاومة الانضغاط والانثناء للخرسانة. من خلال نتائج هذه الدراسة وجد ان الخرسانة الذاتية الرص الحاوية على (5%) من مادة النانوميتاكاؤولين كتعويض جزئي من وزن الاسمنت أعطى أفضل نتائج في الخواص الطرية والميكانيكية لخلطات الخرسانة الذاتية الرص.

الكلمات المفتاحية: النانوميتاكاؤولين، الخرسانة الذاتية الرص، الخواص الطرية والميكانيكية

Introduction

The advantage of adding cementatious materials to very low water/binder ratio concrete mixtures to improve workability. The beneficial effect of adding such a fine powder, by the fact that when cementitious materials particles are well dispersed in cement-water system, they can displace water molecules from the vicinity of cement grains. Entrapped water molecules between flocculated cement particles can be contribute to fluidizing the mixture (Mehta and Monteiro, 2006).

Silica fume particles appear to be perfectly spherical, with diameters ranging from less than (0.1µm) to about (1 to 2µm), so that the average silica fume sphere is 100 times smaller than an average cement particle. Silica fume particles can fill the voids between the larger cement particles. Therefore, owing the reduces both the internal and the superficial bleeding in the mixture. This behavior is very important for micro-structural characteristics of the transition zone between cement paste and aggregate (Khayat, 1996; ASTM C618,2002).

The concept of self-compacting concrete (SCC) resulted from research into underwater concrete, in situ concrete piling and the filling of other inaccessible areas. Highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation (Okamura and Quchi, 2003).

The development of water-reducing superplasticizers meant, high-workability and high-strength concrete could be achieved without excessive cement contents, but excessive segregation and bleeding restricted the use of admixtures to flowing concrete.

In developing SCC, the total fines content of the mix is balanced against aggregate size and grading, in general, the fines content is much higher than in conventional concrete for reasons of stability. The requirement for a high fines content leads to high cement contents, often in the range 450-500 Kg/m^3 (Khayat *et.al.*, 2000; Hendersoon, 2000; Johau and Ban, 2003).

Mineral additives are widely used in SCC, Metakaolin in spite of the more commonly used in SCC, particularly when used with high range water reducing admixture (HRWRA) lead to larger increase in compressive strength of concrete (Obeed, 2007; ACI 211 4R, 2008).

Metakaolin is increasingly being wed to produce high strength, high performance and self-compacting concrete with improved durability. This literature concerning different properties of metakaolin paste and concrete such as porosity, pozzolanic reaction, pore size distribution, compressive strength and durability of metakaolin concrete mixes (Johan, 2003).

Ultra-fine particles binder such as condensed nano-metakaolin have been used in SCC to maintain stability in high workability and higher total binder contents to achieve satisfactory rheology while maintaining segregation resistance (Bartos, 1999).

When nano-particles are used as supplementary cementitious material in concrete, the development of strength bearing crystals of cement paste can be increased or controlled, various improvement can be attained. The nano-particles act as ((nuclei)) of hydration prosses pozzolanic behavior, and can fill the voids in the cement matrix. Nano materials, that exhibit remarkable properties, functionally and phenomena due to the influence of small dimension (Neville,2010; Alaa, 2013; Mohammed, 2015)..

Workability

Advances in admixture technology have played a vital part in the development of SCC. Modern superplasticizers (based on polycarboxylic ethers) promote good workability retention and can be added at any stage of the baching cycle.

Viscosity modifiers can be added to increase the resistance to segregation, while still maintaining high fluidity, allowing concrete to flow through narrow spaces (Okamara and Ouchi, 2003).

To determine the workability of SCC, three different test methods attempted to achieve of the properties of SCC by slump flow, L-box and V-funnel to assess three distinct of fresh SCC, its filling ability, passing ability and segregation resistance.

Materials

1- Cement

When making self-compacting concrete is definitely that of the cement, even when one or two cementitious materials will be used.

The rheological properties of Portland cements are used in low water/cement ratio mixtures in the high presence of a high dosage of superplasticizer (Johan and Ban, 2003). Ordinary Portland cement (OPC) produced by (Tasluja) cement factory is used in this study. Table (1) and Table (2), shows the chemical and physical properties according to the Iraqi specification (IQS No.5:1984).

Table (1) : Chemical analysis of cement

Oxide	Percentage by weight	IQS No.5/1984 Limits
CaO	61.57	
SiO_2	21.3	
Al_2O_3	3.8	
Fe_2O_3	4.6	
MgO	2.1	≤ 5
SO_3	1.55	≤ 2.5 if $C_3A < 5\%$
Loss On Ignition (L.O.I)	2.03	≤ 4
Insoluble Residue (I.R)	0.63	≤ 1.5

Lime Saturation Factor (L.S.F)	0.9	0.66-1.2
C_3S	49.61	
C_2S	23.72	
C_3A	2.3	
C_4AF	13.98	

Table (2) : Physical properties of cement

Physical property	Test result	IQS No. 5:1984 Limits
Specific surface area (cm^2/gm)	3550	Min. 2300
Initial setting time (minute)	97	≥ 45
Final setting time (hours)	4.20	≤ 10
Compressive strength (MPa.) 3days 7days	 23.7 31.2	 > 15 > 23

2- Superplasticizer

The selection of efficient superplasticizer is crucial when making self-compacting concrete. Experience has shown that not all commercial superplasticizer have the same efficiency in dispersing the cement particles within the mix (Uchikawa *et.al.,* 1997; ASTM C494, 2001; Obeed, 2007).

Sulphonated melaimine formaldehyde condenstes which is known (sikament 10 Top) was used throughout this study as a high range water redusing admixture.

3- Fine aggregate

The fine aggregate in self-compacting concrete plays a major role in the workability and stability of the mix (Domone and chai, 1998). Al-Akaidur region sand was used as fine aggregate with (specific gravity, SO_3 % and absorption) equal to (2.64, 0.03%, 0.14%) respectively. Table (3) shown the grading conformed to the (IQS No.45/1984) requirement.

Table (3): Sieve analysis of sand

Sieve size (mm)	Passing %	IQS No.45/1984 Limits (zone 2)
10	100	100
4.75	97.3	90-100
2.36	82.6	75-100
1.18	67.4	55-90
0.6	45.3	35-59
0.3	21.6	8-30
0.15	1.7	0-10

4- Coarse aggregate

Coarse aggregate with a grading similar to that used in conventional concrete may be used in self-compacting concrete (Johan and Ban, 2003). Al-Nebai region crushed gravel was used as coarse aggregate and complying to (IQS No.45/1984) requirements with (specific gravity, SO_3% and absorption) equal to (2.65, 0.018%, 0.06%) respectively. Table (4) shown the sieve analysis of gravel.

Table (4): Sieve analysis of coarse aggregate

Sieve size (mm)	Passing %	IQS No.45/1984 Limits (5-14)mm
20	100	100
14	100	90-100
10	63.8	50-85
5	3.5	0-10

5- Nano-metakaolin

The greatest significant effect when increasing fineness content of concrete is increasing the intensity of the reactions in the hydration process and increases the surface area exposed to reaction with water, this will consequently lead to more hydration products and development in workability and strength. The obvious solution is modify the concrete microstructure, in addition to more homogeneous end product (ACI 211 4R, 2008; Ramezanianpoura and Bahrami, 2012; Mohammed, 2015).

The nano-metakaolin wed in this study of average dimensions (20*100*200) nm supplied by Middle East Mining Investment Company.

Mix Design

The mix design method was based on the fact that self-compacting of concrete can be effected by the characteristics of material and mix proportion . Rational mix design method (Johan and Ban, 2003) was used in this study.

Result And Discussion

- **Fresh concrete**

The fresh concrete is required to change shape under its own weight and mould itself to the formwork in place.

The slump flow and T_{50cm} tests which is filled in one layer without compaction. The spread value results for slump flow and T_{50cm} lie between 735mm and 790mm and (2-5) second respectively as shown in Table (5). The slump flow of (5 NMK, 3 NMK and 1 NMK) is higher than of (PC) mixes by about (15, 11, 7) % respectively. T_{50cm} of SCC containing (5, 3, 1)% nano-metakaolin is less than of conventional self-compacting concrete by about (73, 53, 33) % respectively.

The L-Box test is useful in assessing passing ability and blocking behavior. The heights at either end of the trough (H_1 and H_2) were measured to determine the leveling ability. The blocking ratio of L-Box (H_2 to H_1) is between (0.97 and 1) as shown in Table (6). The blocking ratio (H_2/H_1) of (1 NMK, 3 NMK and 5 NMK) is higher than of (PC) mixes by about (13, 14, 16) % respectively.

The V-funnel test was used to determine the segregation resistance of concrete. Table (7) show the time of concrete flow through the V-funnel and this funnel time is between (6-9) second. The funnel time of (5 NMK, 3 NMK and 1 NMK) mixes is less than of (PC) mixes by about (50, 33, 25)% respectively.

It can be observed from Tables (5), (6) and (7) and Figures (1, 2, 3, and 4) that, the increase in workability can be achieved by incorporating a high volume of ultra fine (nano-metakaolin) in the mix volume of the mortar paste and by use the superplasticizer reduce the water demand. Although fluidity is the characteristic that makes self-compaction concrete attractive, stable, high density and segregation resistance greatly affects the performance of the concrete structure. This agree with Domone and chai,1998; Lars and Goran, 2000; EFNARC, 2002.

Table (5): Slump flow and T_{50cm} results

Mix Notation	Slump flow (mm)	T_{50cm} (second)
PC	685	7.5
1NMK	735	5
3NMK	762	3.5
5NMK	790	2

Table (6): Blocking ratio of L-Box results

Mix Notation	L-Box (Blocking ratio)
PC	0.86
1NMK	0.97
3NMK	0.98
5NMK	1

Table (7): Funnel time of V-funnel result (second)

Mix Notation	Funnel time (second)
PC	12
1NMK	9
3NMK	8
5NMK	6

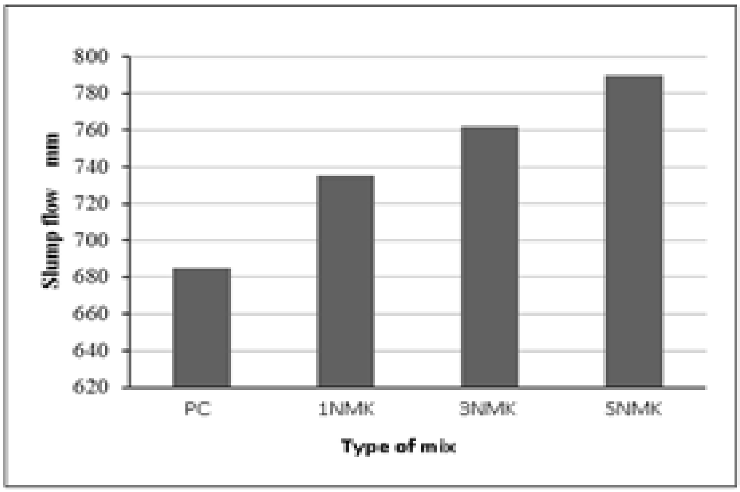

Figure (1): Slump flow for SCC at different percent of NMK

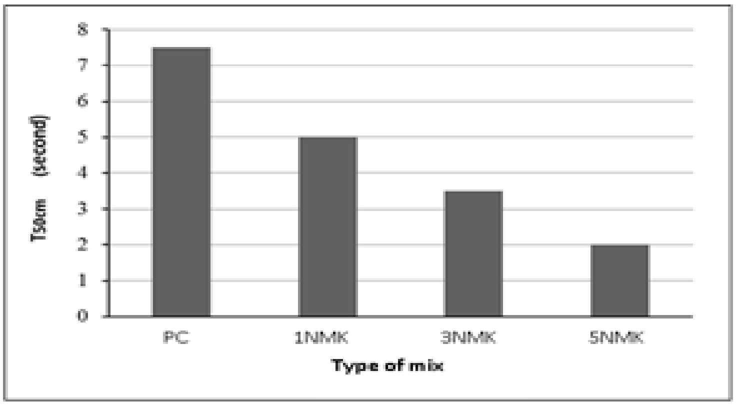

Figure (2): T_{50cm} for SCC at different percent of NMK

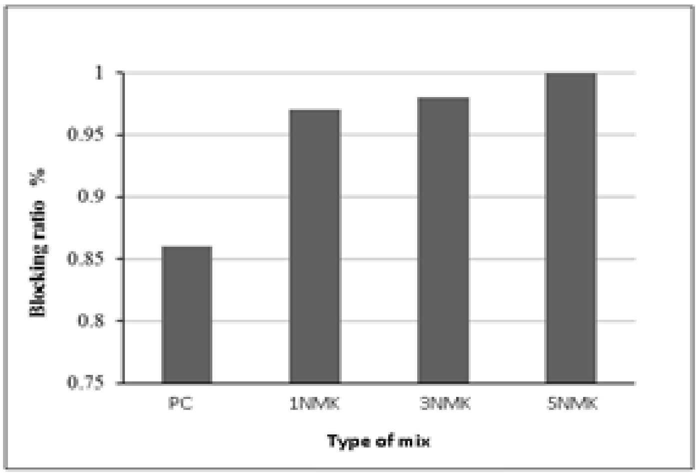

Figure (3): Blocking ratio of L-Box for SCC at different percent of NMK

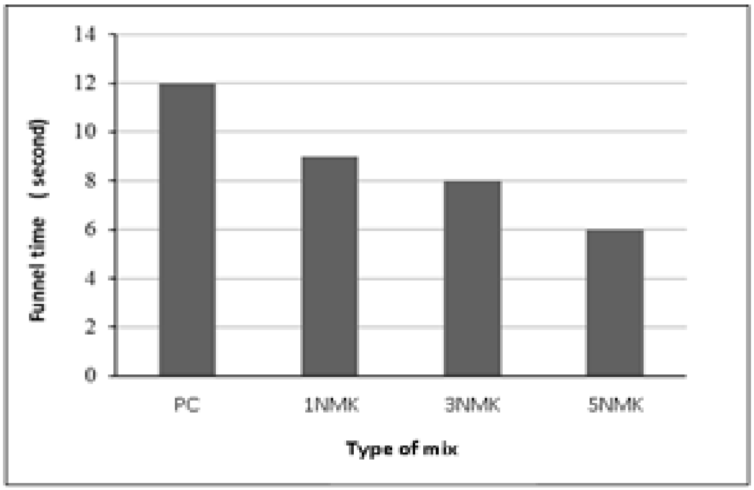

Figure (4): Funnel time of V-funnel for SCC at different percent of NMK

- **Compressive strength**

It can be observed for Table (8) and Figure (5) of concrete cube 10cm at age of (3, 7, 28 and 56) days, the compressive strength of SCC containing nano-metakaolin is usually higher than for conventional concrete. The compressive strength results range from (24 to 35) MPa., (35 to 64) MPa., (71 to 101) MPa. and (78 to 117) MPa.at age (3, 7, 28 and 56) days respectively for (PC, 1NMK, 3NMK, 5NMK) mixes. Compressive strength of (5 NMK, 3 NMK and 1 NMK) is higher than of conventional concrete mixes (PC) by about [(46, 41, 33) %, (83, 51, 30) %, (42, 29, 12) % and (50, 34, 16) %] at ages (3, 7, 28, 56) day respectively. This will encourage homogeneous and denser interfacial zones between the coarse aggregate and the mortar phase (BS 1881. 1989; Gibbs and Zhu, 1999; Kong, 2001).

Table (8): Compressive strength results

Mix Notation	Compressive strength (MPa.)			
	3 days	7 days	28 days	56 days
PC (Reference)	24	35	71	78
1NMK	32	48	80	91
3NMK	34	53	92	105
5NMK	35	64	101	117

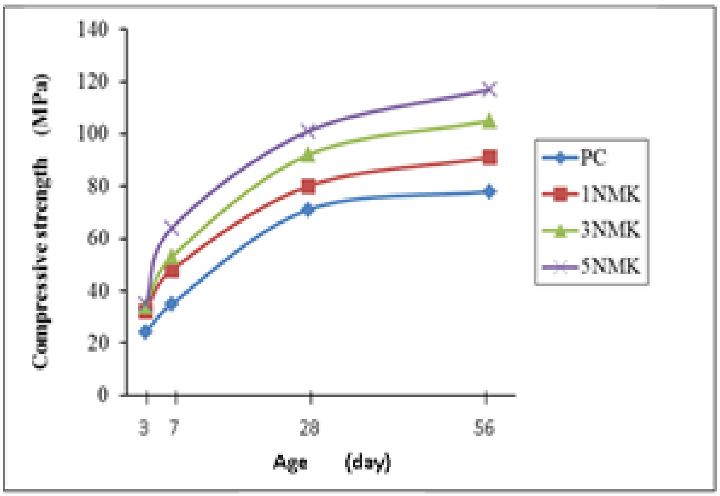

Figure (5): Relation between compressive strength and age for SCC at different percent of NMK

- **Flexural strength**

It can be seen from Table (9) and Figure (6), the SCC mixes containing nano-metakaolin particles achieved significantly higher in flexural strength than the corresponding reference mix due to less pores and micro cracking and more paste in microstructures and help to control the heat of hydration in mixes to achieve satisfactory rheology while maintaining segregation resistance (ASTM C78, 2002, Johan and Ban, 2003; Mohammed, 2015). The flexural strength at ages (28, 56, 90) day of self-compacting concrete containing (1, 3, 5)% nano-metakaolin is higher than of the (PC) mixes by about [(14, 26, 34) %, (20, 14, 50) % and (16, 37, 46) %] respectively.

Table (9): Flexural strength results

Mix Notation	Flexural strength (MPa.)		
	28 days	56 days	90 days
PC (Reference)	6.2	6.5	7.3
1NMK	7.1	7.8	8.5
3NMK	7.8	9.2	10.0
5NMK	8.3	9.8	10.7

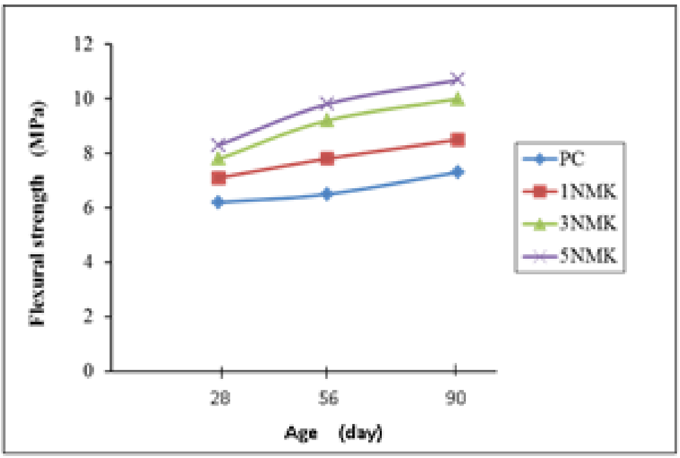

Figure (6): Relation between flexural strength and age for SCC at different percent of NMK

Conclusion

From the results in this research, the following conclusion can be drawn:

1- The properties of both fresh and hardened SCC differences in behavior compared to conventional concretes.

2- The properties of the SCC mixes containing nano-metakaolin were marginally more uniform.

3- It has been observed that the SCC containing nano-metakaolin rather stiff concrete mixes.

4-The change in time of fresh properties of the SCC is an important criterion which will be investigated.

5- The SCC mixes with nano-metakaolin particles, gave an extremely good finish and very smooth surface better than the reference concrete.

6- It could be observed that the quality of the surfaces improved with increased the containing the nano-metacaolin in concrete mixes.

7- The fluidity characteristic greatly affects the properties of the concrete mixes.

References

ACI 211.1R, 2008, "Guide for selecting proportions for high strength concrete using Portland cement and other Cementitious Materials", American Concrete Institute.

ACI 232. IR-00 reproved, 2006, "Use of Raw or Processed Natural Pozzolans in Concrete", American Concrete Institute.

Alaa, M. Rashad, 2013, "A Synopsis About the Effect of Nano-Al_2O_3, Nano-Fe_2O_3, Nano-Fe_3O_4 and Nano-clay on some properties of cementitious materials", A shout guide for civil engineering, materials and design, Vol.52, pp.143-157.

ASTM C494, 2001, "Standard Specification for Chemical Admixtures for Concrete", Vol.04.02,pp.1-9.

ASTM C78, 2002, "Standard Test Method for Flexural Strength if Concrete", American society for Testing and Materials.

BS 1881, part 116, 1989, "Method for Determination of compressive strength of concrete cubes", British standards Institution, pp.3.

Domone, P.L. and Chai, H.W., 1998, "The slump flow test for high workability concrete", cement and concrete Research 28, pp.117-182.

EFNARC guide line achieving the highest standards, 2002 "Specification and Guidelines for self-compacting concrete".

Gibbs, J.C. and Zhu, W., 1999, "Strength of hardend self-compacting concrete", proceedings of first RILEM International symposium of self-compacting concrete, Stockholm.

Henderson, N.A., 2000, "Self-compacting concrete at Millennium point", concrete, pp.26-27.

Iraqi Organization of standards specification, IQS 45:1984, for Aggregate.

Iraqi Organization of standards specification, IQS 5:1984, for Portland cement.

Johan, N. and Ban, S.C., 2003 "Advanced Concrete Technology ", Concrete Properties, London and Edinburgh.

Khayat, K., 1996 "Effect of silica fume on fresh and mechanical properties of concrete", CANMET-ACI Intensive course on fly ash, slag, silica fume, other pozzolanic materials and superplasticizer in concrete, Ottawa, Canada, April, pp34.

Khayat, K.H.; Bickley, J.; Lessard, D., 2000 "Performance of self-consolidating concrete for casting basement and foundation walls", ACI Materials Journal 97, pp.374-380.

Kong, H.J., 2001 "Electrosteric stabilization of heterofloculating alumina/silica suspensions and its application on the development of self-compacting engineered cementitious composities", PhD Thesis.

Lars, M and Goran, T. , 2000 "Guidelines", Task 9, End Product, No.10, Swedish cement and concrete research, pp1-28.

Mehta, P.K. and Monteiro, P.J.M., 2006 "Concrete: Microstructure, Properties and Materials:, Recent Advances and concrete in future, third edition, New York.

Mohammed, K. Abed, 2015 "Behavior of High strength concrete containing Nano-Metakaolin subjected to Fire Flame", PhD Thesis, University of Technology.

Neville, A.M., 2010 "Properties of Concrete", Fourth and final Edition, Wiley, New Yourk and Longman, London.

Obeed A.T., 2007 "Effect of Exposure to Fire Flame on some Mechanical properties of self-compacting concrete using Different Types of Filler", M.Sc Thesis, Babylon University.

Okamura, H and Ouchi, M, 2003 "Mix design for self-compacting concrete", Journal of Advanced Concrete Technology, Vol.1, No.1.

Ramezanianpoura, A.A. and Bahrami, H.J., 2012 "Influence of Metakaolin as supplementary cementing material on strength and durability of concretes", Journal of construction and building materials, Vol.30, pp. 470-479.

Uchikawa, H.; Sone, T. and Sawaki, D., 1997 "A comparative study of the characters and performances of chemical and mixtures of Japanes and Canadian origin", part 2, world Cement Research and Development, pp.70-76.