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Inclusion of nano metaclayed as additive in ultra high performance concrete (UHPC)

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HIGHLIGHTS

- To investigate the effect of nano metaclay in UHPC.
- The investigate the physical, workability, strength and morphology properties of UHPC with the inclusion of nanometaclay.
- To analyse the performance of nano metaclayed UHPC.

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ABSTRACT

The utilisation of Ultra High Performance Concrete (UHPC) tailored with nano materials has growing an interest to the construction. In this research, nano metaclay UHPC mixes were used as additive range from 1, 3, 5, 7 and 9 percent from cement weight. The effect of nano metaclayed UHPC was evaluated in the forms of physical, workability, strength property and morphology of the microstructure in the UHPC and compared to the normal UHPC and metakaolin UHPC. For physical property, the nano metakaolined paste was confirmed using vicat apparatus and determination of fresh property was conducted using slump test. Meanwhile, compressive strength was conducted at 3, 7, 28 and 90, 180 and 365 days of age. The UHPC morphology was analysed using Scanning electron microscope (SEM). It can be concluded that the introduction of nano metaclay in UHPC increase the water demand in UHPC by increase the surface area. For compressive strength, introduction of nano metaclay shows no significant effect at early ages but gradually increase at later ages as compared to the plain UHPC.

1. Introduction

The invention of Ultra High Performance Concrete (UHPC) has started in the 90's. Utilisation of UHPC in construction world overcomes the problem of limited load and durability properties of normal concrete and high strength concrete (HSC). Problem arise using normal concrete and HSC when applies to very extreme condition and unique design structures. Bunker, dam, nuclear plant and other extreme structures must be design with special type of concrete which can resists load more than 100 MPa and also very durable when expose to those extreme condition. This is where UHPC can provide the solutions [1–4]. However, strict procedure and handling must be taken into consideration before choosing UHPC [5–9]. The utilisation of UHPC can be benefits to the industry by providing a smaller design in structures components and resulting in less number of reinforcement. Thus, cost of the construction especially in concrete usage can be minimised [10–12].

Nano material has growing an interest to the researcher especially by providing denser concrete by acting as ultra filler in the microstructure of concrete. In other words, ultra-filling or nano filler effect is the approach nano particles works in the rigid component concrete such as UHPC. Nano silica, nano alumina and titanium oxide are among the nano material used in improving concrete [13–16]. For instance, nano silica can enhanced the performance of concrete by promoting strength enhancement with the influence of smaller size of silica that can produce more nucleation process in the hydration process. The effect as ultra-filler and promoting the nucleation in the cement hydration process is the action that performs by nano silica [11,15]. Apart from that, the effect performs by nano alumina which altering the hydration process which speed up the hardening in CSH particles that can possess early strength effect. Moreover, the inclusion of nano alumina also improves the protection for marine concrete structure by acting as additional layer in the concrete cover

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[15,17,18]. Apart from durability and performance enhancement, nano material can also act as self-cleaning materials [15,19,20]. This can be achieved by inclusion of titanium oxide which widely used in construction industry as protective layer or coatings in concrete structure. Particles of nano which is very fine and smaller than micro based material has the ability to filtrating between cement and hydration gel [3,21,22]. By refining the cement composition in concrete, density and pore will be reduced and automatically a dense concrete can be created. Refining and reducing pore volume in concrete will enhance mechanical and also durability properties of UHPC and also other type of concrete [23–25]. Apart from that, the introduction of nano materials in UHPC is believed to enhance the mechanical properties of UHPC. By utilising this, the structure of C—S—H gel can be improved and refined. This is where the performance of UHPC can be enhanced. Furthermore, better refining of C—S—H gel can helps to achieved better binding in the microstructure of UHPC [3,10,26].

Till now study on the utilisation of nano metaclay in UHPC is still not been done. Due to the potential of nano clay in producing durable and increase strength of concrete, nano metaclay can offer more improvement in concrete and also as an alternative to other nano material. In this research, nano metaclay is developed as nano additive into UHPC. The addition from this research also will contribute on the knowledge and availability of nano clay based materials to be implemented in UHPC and also concrete. It is believed that nano metaclay can performed better or equal to the existing nano material such as nano silica, nano alumina and others.

2. Methodology

2.1. Preparation of nano clay

Nano clay was procured from Sigma Aldrich (M) Sdn Bhd, Malaysia. Based on the technical specification from manufacturer the nano clay size is in the range of 20 nm. Next, calcination process was performed to activate the structure of nano clay into amorphous nano metaclay structure. The duration and temperature of calcination process depends on the purity of kaolin and nano clay [27,28]. For this research, kaolin and nano clay undergoes 3 h duration of calcination and temperature was fixed to 700 °C. After treatment, metakaolin and nano metaclay were formed.

2.2. Preparation for UHPC mixes

Mix constituent for UHPC was finalised based on several trial mixes. Since there was no direct or standard design for UHPC mix, modification was applied based on previous works. The mix design by Matte and Moranville [29] was chosen as a basic mix proportion. The selection of Matte and Moranville [29] because cement content was the lowest as compared to other mixes. Cement content from Matte and Moranville [29] mix was 713 kg/m^3 while most of other researcher reported used more than 1000 kg/m^3 of cement. While Matte and Moranville [30] only used fine aggregates and pure silica sand in their study. Silica fume was added in the mix for strength enhancement and finally heat curing technique was selected [31]. Due to cost and availability of those materials, modification of the existing mix was necessary in order to meet the condition in Malaysia. The final mix proportion is shown in Table 1.1.

Due to low water content which can cause poor workability, cement, water and additive were added first in the mix. The hyperplasticizer was included, so that the paste was uniform and homogenous. Hyperplasticizer used for this research was supplied by BASF (M) type Glenium ACE Suretec 389. The process to blend paste took around 10 min. While mixer was running fine aggregate was poured and the mixer continued to rotate about 6 min. Finally coarse aggregate was added and mix for 5 min. The total duration for mixing UHPC mix is around 25 min. Preparation of nano metaclayed UHPC mix which also includes nano metaclayed as additives from the range 1%, 3%, 5%, 7% and 9% from cement weight were introduced. All nano metaclayed UHPC specimens were compared to those normal UHPC and also metakaolin UHPC and the morphology it's confirmed by using SEM method. For metakaolin uhpc mix the level of replacement was fixed to 10% from cement weight without the addition of nano metaclay.

2.3. Preparation for fresh, strength and morphology properties

Before mixing the UHPC, the fresh property of metakaolin and nano metaclayed cement was done by setting time testing using vicat apparatus. The standard for setting time analysis was accordance to BS EN 196-3:2016. From this experiment the water demand and time setting for metakaolin and nano metaclayed in the cement structure can be discussed. Immediately after mixing, the fresh UHPC specimens were tested its workability using slump test and accordance to BS EN 12350-2:2009. After UHPC mixes already prepared and tested its workability, UHPC specimen were transferred to mould. To determine the compressive strength, 100 mm cube was used confirmed according to BS EN 12390-3:2009 and the final reading was confirmed based on an average from three cubes for every age of testing. Finally the morphology property was evaluated using Scanning Electron Microscope (SEM) and the scale for all images was fixed to 30 μm meter (μm) using Toshiba tabletop SEM instrument.

3. Result and discussion

3.1. Analysis of physical property of OPC, metakaolin and nanometaclay paste

The effect on physical property of OPC, metakaolin and nanometaclay in UHPC is shown in Fig. 1.1. The physical properties for all specimens were evaluated in terms of water demand and setting time of paste. The water demand was increased gradually concurrently with the increased level of percentage for nano metaclay. OPC recorded 155 g of water as compared to the metakaolin paste that marked 160 g of water. Meanwhile, nano metaclay spec-

Table 1.1
Series of mix proportion for nano based UHPC.

Specimen	Cement (kg/m^3)	Water (kg/m^3)	Hyper Plasticizer (kg/m^3)	Coarse (kg/m^3)	Fine (kg/m^3)	MK (kg/m^3)	NMC (kg/m^3)
OPC	800	160	16	800	433	0	0
MK10	720					80	0
NMC1						80	8
NMC3						80	24
NMC5						80	40
NMC7						80	56
NMC9						80	72

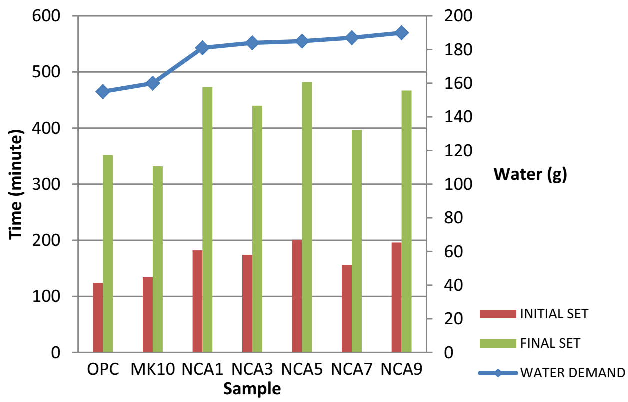

Fig. 1.1. Standard consistency and setting time for OPC, metakaolin and nanometaclay paste.

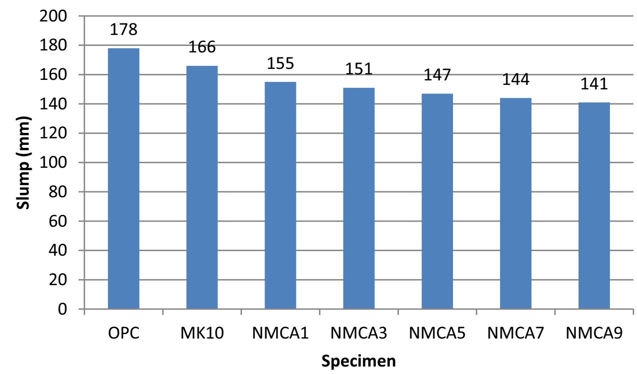

Fig. 1.2. Workability of normal UHPC, Metakaolined UHPC and Nano metaclayed UHPC.

imens at every level of percentage addition from 1, 3, 5, 7 and 9 percent recorded the increased in water at 181 g, 184 g, 185 g, 187 g and 190 g, respectively. Obviously from this pattern, we can see that nano particle of nano metaclay paste increased the surface area of cement paste due to its nano particles as compared to the metakaolin paste which in micro particles and also OPC paste which in macron particles. Finer particles performs by nano metaclay contributes to the increased in the surface area thus; cement paste need more water to maintained its freshness. Apart from that, metakaolin which in micro particles also shown an increased in water demand as compared to the OPC. Although the water needed by metakaolin is not as high as compared to nano metaclay, proves that particles size of materials play a major role to determine the optimum consistency level for cement paste [32,33].

In Fig. 1.1 also depicts the result for setting time analysis. It shown that due to increased in surface area performs by nano metaclay, the cementitious binder also retard and performs delayed action in the process while transforming from liquid to solid. It can be seen clearly that metakaolin performs accelerating effect in the hardening process as compared to the nano metaclayed and also OPC. The delayed in setting period performs by nano metaclay was contributed by increased in water demand that been proved in standard consistency testing. The increase in water demand was expected and contributed from the nano particles of nanometaclay which need more water to maintained its consistency period. The delayed action was performed from the effect of metakaolin in the same mix with nanometaclay which acts as replacement agent. Since there was a combination of metakaolin and nanometaclay in the same mix, densifying effect in the paste was increased and more water was needed and resulting in delay in setting period. From this finding it can be concluded that the introduction of nano metaclay in cement paste as additive and also metakaolin as replacement material delayed the setting period as compared to OPC and metakaolin paste. Due to this, it is recommended that when dealing with finer particles such as nano in mixing concrete, the addition of admixture either in chemical or powder form need to be tailored and alter together with nano particles. This is to ensure that the problem arise such as low workability and resulting to segregation and bleeding that can cause poor performance of UHPC or concrete at later ages.

3.2. Analysis of workability for normal UHPC, metakaolined UHPC and nanometaclayed UHPC

Fig. 1.2 portrait the slump analysis for OPC, metakaolined and nano metaclayed UHPC mixes. From this figure shows a gradually decrease value of slump starting from OPC, metakaolined and also nano metaclayed UHPC mixes. The highest slump was recorded by OPC and followed by MK10, NMCA1, NMCA3, NMCA5, NMCA7 and NMCA9 mix which marked the slump at 178 mm, 166 mm, 155 mm, 151 mm, 147 mm, 144 mm and 141 mm, respectively. From Fig. 1.2 shows that influence of micro and nano particles in concrete affected the workability of UHPC. This was confirmed by the gradually decreasing value of slump recorded and presented in this figure. This finding clearly shows that the inclusion of micro and nano particles in concrete reduces the workability of UHPC. To note, this action occurred due to the increased of surface area performs by micro and nano particles from metakaolin and nanometaclay. More surface area provided by metakolin and nano metaclay in UHPC resulting in reduction in workability due to UHPC mixes needs additional time to blend and pair with the metakaolin and nano metaclay. Although slump shows a decrease pattern, the characteristics slump in early design which is 60–180 mm height is still within the range. Moreover, the origin of metakaolin and nano metaclay which was from clay provides absorption effect that will reduce the water content in the UHPC mixes. This also contributes to the reduction in slump especially when dealing with UHPC mixes which the water content is below than 0.3. Furthermore, this explains on the decreased pattern at every higher level of nano metaclay tailored in UHPC mixes. As conclusion, nano particles reduced the workability effect due to the increased surface area which needs to be covered by cement particles. This effect needs to be improved by introducing chemical admixtures which can acts as dispersing action to soften and breaking the nano particles and immediately interact with cement.

3.3. Analysis of strength property of normal UHPC, metakaolined UHPC and nano metaclayed UHPC

To evaluate the strength property, a compressive strength was selected as indicator to be measured. In this case, all nano metaclayed specimens were compared to a normal UHPC which was designated as OPC and metakaolined UHPC designated as MK10. For nano metaclayed UHPC, all specimens were coded with NMCA and the value behind the code representing the percentage of nano metaclay as additive. The details were presented in Fig. 1.3.

Fig. 1.3 shows the effect of nano metaclayed in UHPC at day 3, 7, 28, 90, 180 and 365 days. Generally, the inclusion of nano metaclay in UHPC shows a retarding effect in strength property. This was portrayed from day 3 until 28 days which shows reduction in compressive strength for all nano metaclayed UHPC as compared to the plain UHPC and Metakaolined UHPC. The retarding or slow effect in strength performed by all nano metaclayed UHPC was contributed by several factors. Firstly, the shape and surface texture for nano

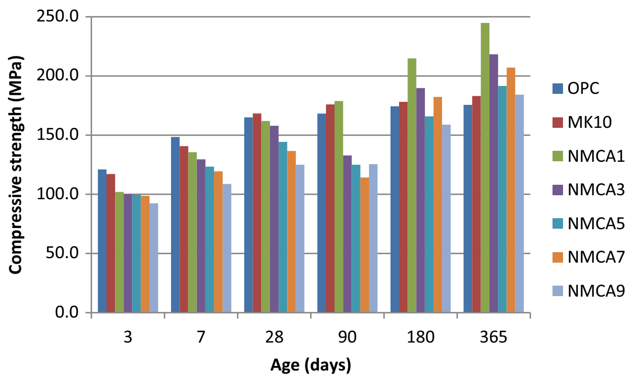

Fig. 1.3. Compressive strength for normal UHPC, Metakaolined UHPC and Nano Metaclayed UHPC.

clay which was rounded and rough surface [15,34]. Due to this, the rough surface of nano metaclay limits the mobility in the cement paste. Although rounded shape proved to increased the mobility of concrete, the ball bearing affect did not contribute to uniformly tailor the nano metaclay with the cement particles [35,36]. Furthermore, nano clay origin which from clay provided absorption effect and affected the water level in concrete which affected the binder materials. Apart from that, due to absorption and rounded shape of nano metaclay, creates flocculation or unhydrated particles. The flocculation of nano metaclay in the transition zone cement will block the pozzolanic reaction between cement and nano metaclay resulting in strength reduction and UHPC will not perform optimally at this particular ages. Those flocculated materials will perform incomplete combination and the role of nano metaclay at this period was only as filler. However, for metakaolined UHPC the behaviour of compressive strength did not retard the strength but surprisingly the optimum strength was the highest among other UHPC specimens. At this particular period (day 3 until day 28) metakaolin reaction as micro filler and those actions occurred at day 3 which promoting reaction of hydrated structure with cement. Next, at 7 to 14 days of age, which created pozzolanic reaction with cement and enhanced strength of UHPC [37,38]. This trend occurred due to shape of metakaolin which is thin and flaky particles that can easily acting as needle and bind with cement.

However, the strength for nano metaclayed UHPC start to performs high compressive strength at age 90 days and continuously increased until 365 days of age. This pattern can be seen in Fig. 1.3 and the highest strength was recorded by NMCA1 and followed by MK10, OPC, NMCA3 NMCA5, NMCA9 and NMCA7 with compressive strength marked at 179 MPa, 176 MPa, 168 MPa, 132 MPa, 125 MPa, 126 MPa and 114 MPa respectively. The strength increment at this age was contributed by secondary nucleation possesses by the nano filler effect from nano metaclay. The particles of nano metaclay reacted with C—S—H gel or binder and chemically start the secondary hydration process. Thus, strength of UHPC increased drastically. The action of secondary hydration product only occurred due to the effect causes from nano material [32,39]. In nano particles reactions, some of nano materials performs retarding effect when combines with cement. This happens due to the nano particles shape and surface texture that refined the hydration product known as C—S—H gel at first phase. The refinement process in the structure of C—S—H gel was occurred by nano metaclay and after the process was completed, second phase of the chemical reaction started which is known as nucleation process. This reaction took place in the microstructure of C—S—H gel and strength increment was triggered by the nano metaclay from the non-completed hydration process in the microstructure of C—S—H gel. We can see clearly that secondary hydration product or nucleation increased drastically at 180 until 365 days of age. The highest compressive strength was recorded by NMCA1 at 245 MPa and the gap of strength between NMCA1 mixes as compared to the other UHPC mixes is enormous. It can be concluded that the reaction of nano metaclyed in UHPC performs slow effect in strength enhancement as compared to the normal UHPC and also metakaolined UHPC. The slow reaction of nano metaclay was contributed by the high amount of cement in UHPC which the reaction was prolong due to the compact and low water uses in UHPC system. With the nano particles in the UHPC, the hydration process was delayed and the role of nano metaclay only as filler agent in the binder. So the action of nano metaclay in UHPC acted in 2 phases. First, as nano filler which the action was to refined the high amount of cement in UHPC. The actions start at day 3 until day 28. During this period, strength enhancement was not optimum due to time taken for nano metaclay to acts as refinement agent. Second, nucleation or second hydration process which occurred at day 90 and continues until 365 days of age. During this period, the refinement process in the hydration gel started to performs the additional Calcium Silica hydrated process. Due to this action, strength enhancement gradually increased and the performance of UHPC was improved [40,41].

3.4. Analysis of micrograph images for normal UHPC, metakaolined UHPC and nano metaclayed UHPC

Fig. 1.4 shows the micrograph images for UHPC specimens at day 3. At a glance the surface analysis for all UHPC specimens can be classified as rough and irregular surfaces. The binder formation of C-S-H gel clearly can be seen in Fig. 1.4a which surrounding the aggregate particles. The effect seen in this figure promoted the strength at early ages. Although the surface refinement between the aggregate particles was not clear, the binder starts to form and clearly covered the aggregate particles and can be visualised with coarser particle in Fig. 1.4a. This coarser particle due to age will be refined and strength enhancement can be marked. Different image was portrayed in Fig. 1.4b with the inclusion of metakaolin in the UHPC. The action of micro filler can be seen clearly in this figure from less coarser surface which covered by metakaolin. At this age, the strength development was triggered from the filler effect. Due to that, strength enhancement from the reaction of metakaolin and cement was not created. In other words, the inclusion of metakaolin at this age can be called as dilution effect. This dilution effect caused by metakaolin delayed the strength due to high cement content in the UHPC system. This dilution effect can be seen again in Fig. 1.4c until 1.4 g which represents nano metaclay in UHPC. Consequently, nano metaclay increase the effect of dilution effect in the UHPC. This can be seen from the sharp edges that perform by the action from nano metaclay with cement. Due to this effect, strength enhancement due to the inclusion of nano metaclay is not fully executed. The inclusion of nano metaclay at this age acting as nano filler and refine the surface of C—S—H gel. Since size of nano particle by nano metaclay was smaller than OPC and metakaolin, the refinement process will be longer due to increased in surface area and strength enhancement was suspected to be lowered as compared to the normal UHPC and also metakaolined UHPC.

Fig. 1.5a until 1.5 g shows the effect of normal, metakaolined and nano metaclayed UHPC at day 28. At a glance the reaction occurred for all UHPC system called as pozzolanic reaction of silica and alumina for metakolin and nano metaclay. For normal UHPC, the strength enhancement was contributed from the complete binder process of C—S—H gel. For normal UHPC the surface of UHPC shows a refinement at surface as shows in Fig. 1.4a. The refinement of the surface can be seen in Fig. 1.5a by less coarser surface created at this age. Most of the coarser particle which the surface

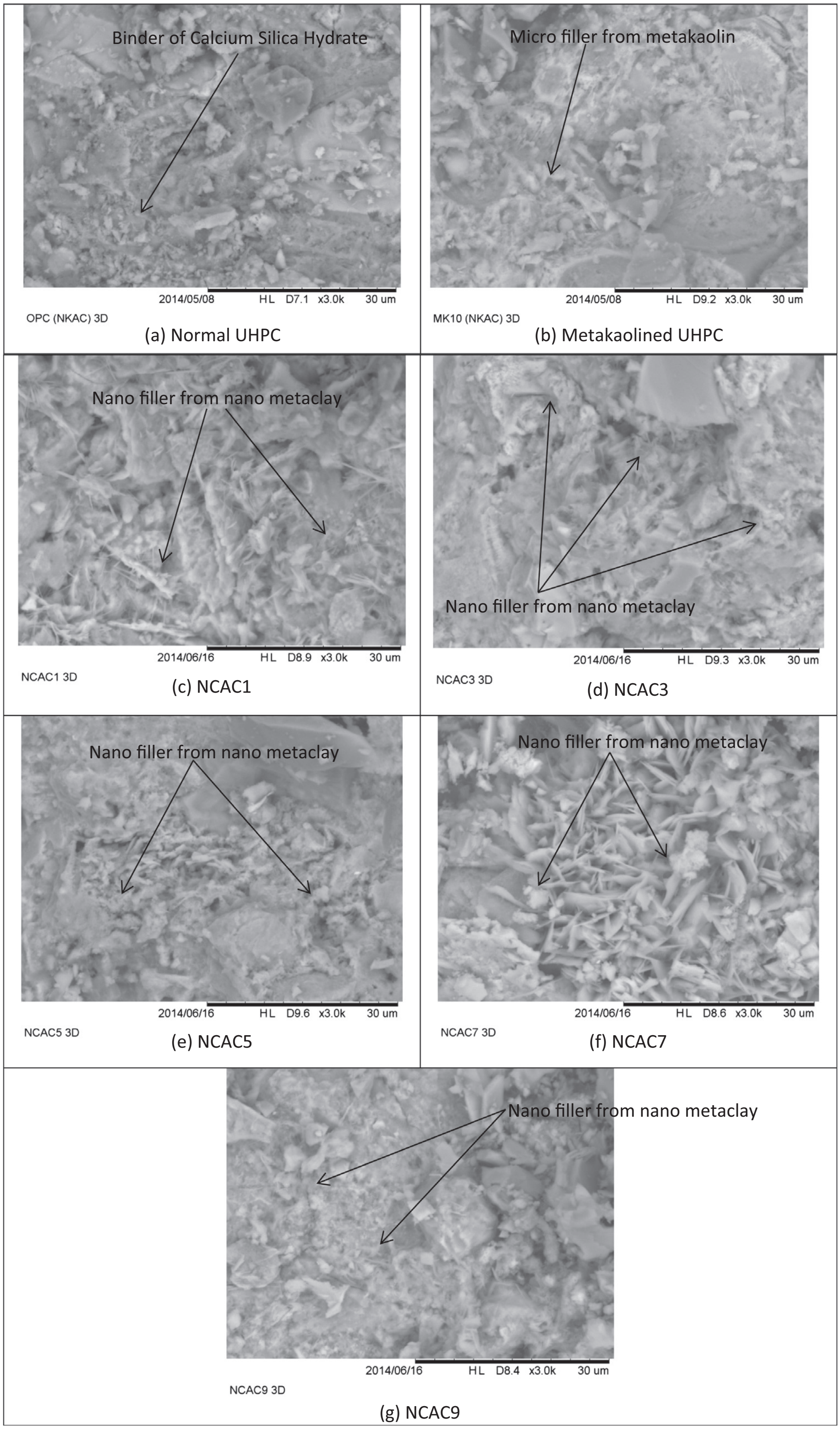

Fig. 1.4. Micrograph images for normal UHPC, Metakaolined UHPC and Nano Metaclayed UHPC at day 3.

pores is visible was covered by C—S—H gel which also influence the strength enhancement performs by normal UHPC as compared to the other UHPC mixes. However, for metakaolined and nano metaclayed UHPC, the strength enhancement was promoted from the filler action during the early ages. Those particles of nano metaclay slowly react with cement and perform pozzolanic reaction. The pozzolanic reaction was showed in the Fig. 1.5b until 1.5 g only the differences were showed by the way the particles were per-

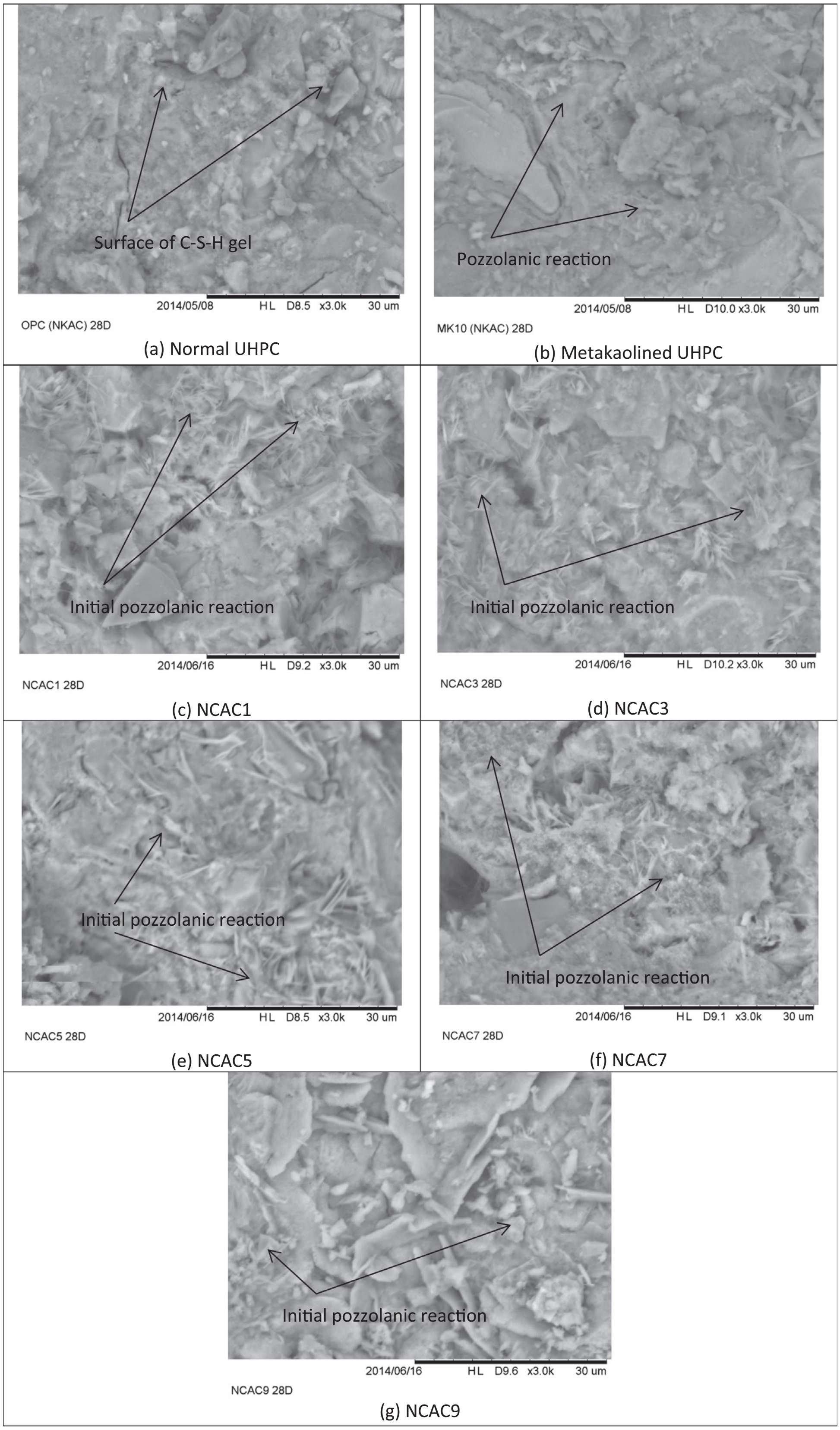

Fig. 1.5. Micrograph images for normal UHPC, Metakolined UHPC and Nano Metaclayed UHPC at day 28.

formed in the cement composition. The pozzolanic reaction caused by metakaolin was showed by the smoother surface of UHPC mix which cannot be detected in the normal UHPC and also all nano metaclayed UHPC respectively. For nano metaclay, the pozzolanic reaction was showed from a tiny needle which can be seen in Fig. 1.5 until 1.5 g. That composition was suspected to be as a way for nano metaclay transformed from ball bearing effect as nano filler into pozzolanic reaction amorphous structure acting

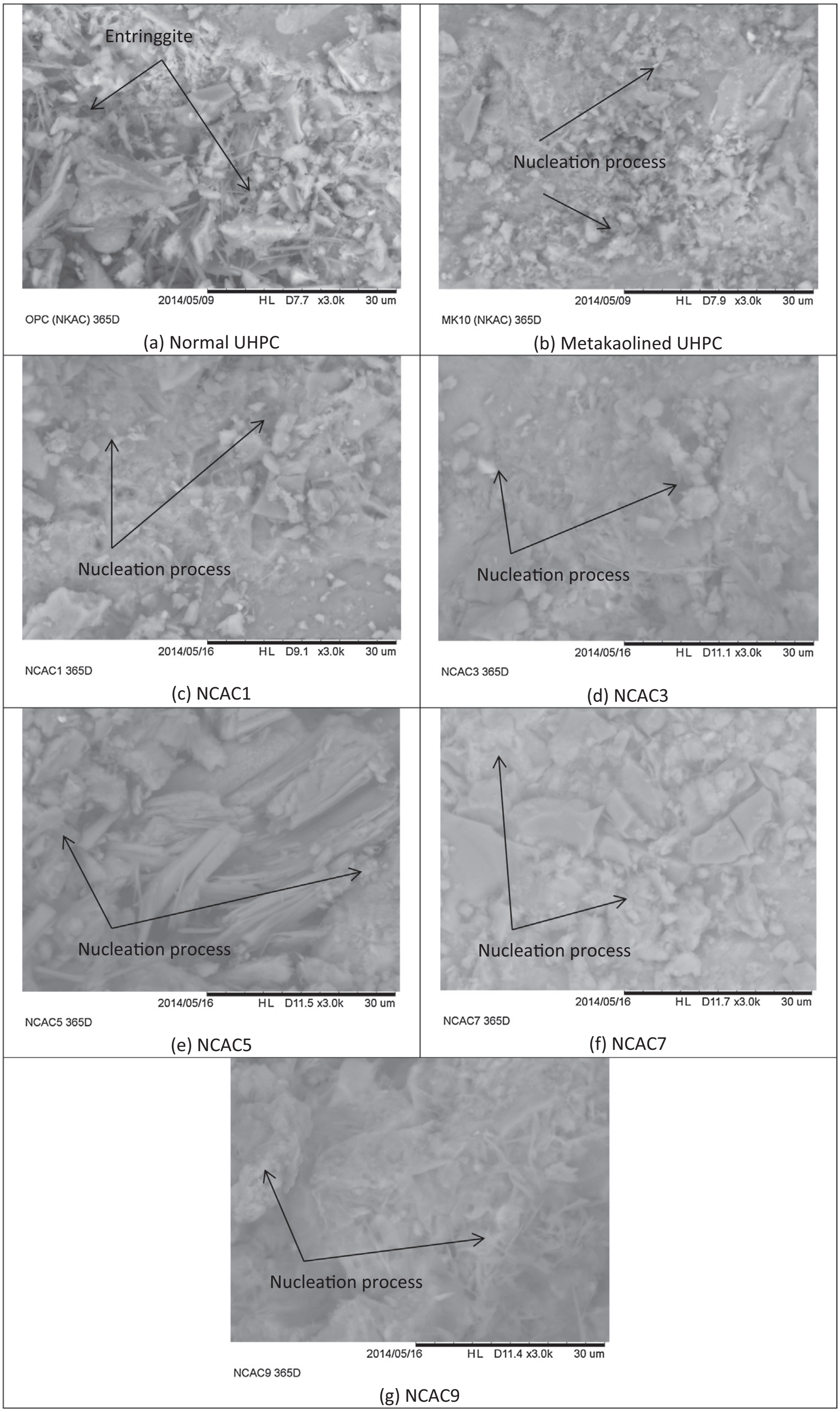

Fig. 1.6. Micrograph images for Normal UHPC, Metakaolined UHPC and Nano Metaclayed UHPC.

as bonding or interlock with the existing C—S—H gel [11,15,42,43]. The tiny needle actions of pozzolanic reaction for NCAC1 until NCAC5 were spotted from smaller sharp edges formation in between C—S—H gel. Eventually, for NCAC7 and NCAC9, the reaction of sharp needle edges was seen growing and expanding as compared to the NCAC1 until NCAC5 mixes. The increased in size for pozzolanic reaction by NCAC7 and NCAC9 created a bridging effect which promoted the void between C—S—H gels. The bridging effect caused a week spots between the transition zone of cement and aggregates and affected the bonding between C—S—H gels. This phenomena supported the low strength development performed by those two mixes. Apart from that, at higher addition of nano metaclay, development of strength does not enhanced the UHPC properties due to the dilution effect which was not settled starting from day 3.

The microstructure of UHPC specimens at 365 days were portrayed in Fig. 1.6a until 1.6 g. Generally, the surface of UHPC specimens especially for nano metaclay shows a refinement and fewer pores created and compared to the normal UHPC. Fig. 1.6a represent normal UHPC which no inclusion of nano metaclay or metakaolin. The surface of normal UHPC were marked with many pores which formed the bridging effect caused by entringgite that caused refinement in the formation of binder. The bridging effect can be seen obstructive the bonding between binder. Due to this formation, strength development performed by normal UHPC was lowered as compared to metakaolined and nano metclayed UHPC. For normal UHPC the binder formation already slow after 180 days of age. Due to that, when UHPC was subjected to loading the pores created between the bridging effect will breaks easily due to amorphous formation of crystalline hydration gel. Eventually, the surface of metakaolined UHPC represent in Fig. 1.6b shows a neat surface of UHPC microstructure. The refinement of UHPC surface was contributed by secondary hydration process called as nucleation process. The nucleation process can be seen altered the surface of C—S—H gel and less pores were spotted. Due to the refinement process and also secondary hydration process, strength enhancement can be expected and this supported the findings in compressive strength analysis in previous section. For nano metaclayed UHPC specimens, the secondary hydration process or nucleation was spotted at the surface of C—S—H gel. The size of nucleation was smaller as compared to the metakaolin. This occurs due to nano size of nano metaclay helps to refine the surface and then promoted hydration process. This is the factor that contributed to the strength enhancement with nano metaclay in the UHPC system. However, increase the percentage of nano metaclay shows that the refinement was delayed due to increased numbers of nano metaclay. This can be seen in the surface of NCAC5, NCAC 7 and NCAC9 which the surface is not as smooth and uniform as compared to NCAC1 and NCAC3. Thus, strength enhancement was delayed. This action was contributed by ultra filler from nano metaclay. Due to this action, the strength development of nano metaclayed UHPC was increased and highest compressive strength recorded was performed by NCAC1 which the introduction of nano metaclay at 1% only. The inclusion of nano metaclay in the UHPC created nucleation in refining the C—S—H gel. This action occurred after 180 days and the performance of UHPC can be prolonged.

4. Conclusion

From this study, the conclusions are drawn as follows:

1. The inclusion of nano metaclay in cement paste creates retarding effect in paste. The retarding effect was contributed due to increase of surface area from the nano particles of nano metaclay. Apart from that, hardening period of paste containing nano metaclay was also delayed as compared to metakaolin and also normal pastes.
2. Inclusion of nano metaclay in UHPC enhances properties of UHPC at late ages. The introduction of nano metaclay also provides as retarding the workability of UHPC mixes. This action was occurred from the nano filler of nano metaclay as compared to the normal and metakaolined UHPC mixes.
3. Strength development of nano metaclayed UHPC was seen at later ages. The action causes by nano metaclay in UHPC were filler effect, pozzolanic reaction and finally secondary hydration process or nucleation process.

Conflict of interest

None.

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References

[1] P. Richard, M. Cheyrezy, Composition of reactive powder concretes, Cem. Concr. Res. 25 (7) (1995) 1501–1511.
[2] M.G. Lee, Y.C. Wang, C.T. Chiu, A preliminary study of reactive powder concrete as a new repair material, Constr. Build. Mater. 21 (2007) 182–189.
[3] N.K. Lee et al., Uncovering the role of micro silica in hydration of ultra-high performance concrete (UHPC), Cem. Concr. Res. 104 (2018) 68–79.
[4] M.M. Reda, N.G. Shrive, J.E. Gillott, Microstructural investigation of innovative UHPC, Cem. Concr. Res. 29 (3) (1999) 323–329.
[5] Lehmann, C., P. Fontana, and U. Müller, Evolution of Phases and Micro Structure in Hydrothermally Cured Ultra-High Performance Concrete (UHPC), in Nanotechnology in Construction 32009, Springer Berlin Heidelberg: Federal Institute for Materials Research and Testing (BAM), Berlin, Germany
[6] Khurana, R., R. Magarotto, and S. Moro, User Friendly Ultra High Performance Concrete (UHPC), 2010.
[7] C. Selleng et al., Influencing factors for the effectivity of heat treatment of ultrahigh performance concrete (UHPC), Beton- Stahlbetonbau 112 (1) (2017) 12–21.
[8] Michael. Schmidt, et al., Ultra-High Performance Concrete and Nanotechnology in Construction. Proceedings of Hipermat 2012. 3rd International Symposium on UHPC and Nanotechnology for High Performance Construction Materials2012: kassel university press GmbH.
[9] S. Pyo, Characteristics of ultra high performance concrete subjected to dynamic loading, University of Michigan: Ann Arbor, 2014, p. 209.
[10] M.S.M. Norhasri et al., Inclusion of nano metakaolin as additive in ultra high performance concrete (UHPC), Constr. Build. Mater. 127 (2016) 167–175.
[11] M. Gesoglu et al., Properties of low binder ultra-high performance cementitious composites: comparison of nanosilica and microsilica, Constr. Build. Mater. 102 (2016) 706–713.
[12] A.L. Hoang, E. Fehling, A review and analysis of circular UHPC filled steel tube columns under axial loading, Struct. Eng. Mech. 62 (4) (2017) 417–430.
[13] K. Sobolev, The development of a new method for the proportioning of high-performance concrete mixtures, Cem. Concr. Compos. 26 (7) (2004) 901–907.
[14] Sobolev, K., et al., Nanomaterials and Nanotechnology for High-Composites. SP-254—8. Nanotechnology of Concrete: Recent Developments and Future Perspectives. ACI. K. Sobolev and S.P. Shah pp. 93 – 120, 2008.
[15] M.S.M. Norhasri, M.S. Hamidah, A.M. Fadzil, Applications of using nano material in concrete: a review, Constr. Build. Mater. 133 (2017) 91–97.
[16] G. Xiaoyu, F. Yingfang, L. Haiyang, The compressive behavior of cement mortar with the addition of nano metakaolin, Nanomater. Nanotechnol. 8 (2018).
[17] K. Wille, C. Boisvert-Cotulio, Material efficiency in the design of ultra-high performance concrete, Constr. Build. Mater. 86 (2015) 33–43.
[18] A. Akbari, A. Modarres, Evaluating the effect of nano-clay and nano-alumina on the fatigue response of bitumen using strain and time sweep tests, Int. J. Fatigue 114 (2018) 311–322.
[19] L. Evelson, N. Lukuttsova, Some practical aspects of fractal simulation of structure of nano-modified concrete, Int. J. Appl. Eng. Res. 10 (19) (2015) 40454–40456.
[20] P. Maravelaki-Kalaitzaki et al., Physico-chemical and mechanical characterization of hydraulic mortars containing nano-titania for restoration applications, Cem. Concr. Compos. 36 (1) (2013) 33–41.
[21] Guterrez, K.S.a.M.F. How Nanotechnology can change the Concrete World. 2005.
[22] I.G. Richardson, The nature of C-S-H in hardened cements, Cem. Concr. Res. 29 (8) (1999) 1131–1147.
[23] C. Wang et al., Preparation of Ultra-High Performance Concrete with common technology and materials, Cem. Concr. Compos. 34 (4) (2012) 538–544.
[24] V. Rahhal et al., Role of the filler on Portland cement hydration at early ages, Constr. Build. Mater. 27 (1) (2012) 82–90.
[25] P.C. Aitcin, Cements of yesterday and today: concrete of tomorrow, Cem. Concr. Res. 30 (9) (2000) 1349–1359.

[26] M.S. Muhd Norhasri, M.S. Hamidah, A. Mohd Fadzil ICMDPE 20132014, in: Morphology and Strength of Cement Paste from Clay as Nano Material, 2nd International Conference on Mechanical Design and Power Engineering, Beijing, 2013, pp. 19–24.
[27] V. Matějka et al., Metakaolinite/TiO2 composite: Photoactive admixture for building materials based on Portland cement binder, Constr. Build. Mater. 35 (2012) 38–44.
[28] H. Shoukry et al., Flexural strength and physical properties of fiber reinforced nano metakaolin cementitious surface compound, Constr. Build. Mater. 43 (2013) 453–460.
[29] V. Matte, M. Moranville, Durability of reactive powder composites: influence of silica fume on the leaching properties of very low water/binder pastes, Cem. Concr. Compos. 21 (1) (1999) 1–9.
[30] V. Matte, M. Moranville, Durability of reactive powder composites: influence of silica fume on the leaching properties of very low water/binder pastes, Cem. Concr. Compos. 21 (1999) 1–9.
[31] A.K. Nanda, P.P. Bansal, M. Kumar, Effect of nano silica and silica fume on durability properties of high performance concrete, Int. J. Civ. Eng. Technol. 9 (2) (2018) 115–129.
[32] M.A. Kewalramani, Z.I. Syed, Application of nanomaterials to enhance microstructure and mechanical properties of concrete, Int. J. Integr. Eng. 10 (2) (2018) 98–104.
[33] G. Baskar, P. Brightson, S.B. Gnanappa, Impact of nano composites concrete on sustainable environment, J. Comput. Theor. Nanosci. 15 (1) (2018) 360–363.
[34] R. Rafiee, R. Shahzadi, Mechanical properties of nanoclay and nanoclay reinforced polymers: a review, Polym. Compos. (2018).
[35] M.S. Vijaykumar et al., Development and testing of nano-clay composites for pressure pad application, Int. J. Veh. Struct. Syst. 10 (2) (2018) 103–107.
[36] M.R. Irshidat, M.H. Al-Saleh, Thermal performance and fire resistance of nanoclay modified cementitious materials, Constr. Build. Mater. 159 (2018) 213–219.
[37] O.R. Alonge, M.B. Ramli, T.J. Lawalson, Properties of hybrid cementitious composite with metakaolin, nanosilica and epoxy, Constr. Build. Mater. 155 (2017) 740–750.
[38] G. Barluenga, I. Palomar, J. Puentes, Hardened properties and microstructure of SCC with mineral additions, Constr. Build. Mater. 94 (2015) 728–736.
[39] M.H. Gabr, K. Uzawa, Mechanical, thermal, and interfacial shear properties of polyamide/nanoclay nanocomposites: study the effect of nanoclay on the micromechanism of fracture, J. Thermoplast. Compos. Mater. 31 (4) (2018) 447–464.
[40] R. Yu, P. Spiesz, H.J.H. Brouwers, Effect of nano-silica on the hydration and microstructure development of ultra-high performance concrete (UHPC) with a low binder amount, Constr. Build. Mater. 65 (2014) 140–150.
[41] W. Li et al., Effects of nano-silica and nano-limestone on flowability and mechanical properties of ultra-high-performance concrete matrix, Constr. Build. Mater. 95 (2015) 366–374.
[42] A. Machner et al., Limitations of the hydrotalcite formation in Portland composite cement pastes containing dolomite and metakaolin, Cem. Concr. Res. 105 (2018) 1–17.
[43] M. Fitos et al., Pozzolanic activity of thermally and mechanically treated kaolins of hydrothermal origin, Appl. Clay Sci. 116–117 (2015) 182–192.