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Performance Optimization of Elastomeric Latexes in Cement Concrete Production

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Abstract: At present, elastomeric latexes, which mainly consist of hydrocarbon substances, are being increasingly used in civil engineering applications as modifiers, especially for the purpose of improving performance of hydraulic cement concrete. However, unlike most cement concrete modifiers, where the normal production process is barely unchanged, inclusion of elastomers into cement concrete, requires additional techniques to the conventional production process. This paper reports experimental findings regarding extra production techniques for optimum performance in latex-modified concrete. To identify and categorize the most effective approach, a series of normal and latex-modified concretes were designed and produced based on conventional as well as modified production processes. In the process, the roles of mixing procedure, workability, setting time, water/cement ratio, latex dosage and curing regime were studied. Homogeneity in latex-cement blends was monitored through endothermic activities of differential scanning calorimetry. In addition, superiority among specimens was assessed through compressive strength. Results show that performance of latex-modified concrete depends largely on the techniques involved in the mixing procedure, water/cement ratio, latex content and curing regime. Thus, unless normal practices involved in the production of conventional concrete are appropriately adjusted, the optimum performance of elastomeric concrete may never be achieved.

Key words: Latex-modified concrete, hydrocarbon substances, optimum performance, differential scanning calorimetry, compressive strength

INTRODUCTION

Since the evolution of hydraulic cement concrete, its production process has been regarded as one of the key factors affecting the desired strength and durability. To emphasize on the importance of production process, operational procedures, which include, batching, mixing, casting, compaction and curing, were specified by various ‘Standards’ such as British Standard (BS) and American Society for Testing and Materials (ASTM). In fact, strict adherence to the stipulated production instructions found in the various ‘Standards’ is generally considered as the main gateway to the achievement of a strong and durable concrete.

Inclusion of polymeric substances was one of the prominent recommendations for enhancing general performance of concrete, especially cement and asphalt concretes (Rajni *et al*., 2006; Haggam *et al*., 2014). The first patent with the present concept of polymer latex-modified system was published by Lefebvre and Natural Rubber Latex (NRL) was used as the modifier in the study (Ohama, 1995). Since then, investigations on potential natural rubber (Mathew *et al*., 2001; Qi *et al*., 2014) and synthetic latexes (Barluenga and Hermandez-Olivares, 2004) were conducted throughout the world. Presently, many effective polymer systems for cement, concrete and mortar have been developed and are already in use in various applications of concrete and mortar (Pieming and Wang, 2007; Ohama, 2007). Indeed, among the several polymeric substances used in practice, elastomeric latexes are the most frequently applied (Bala, 2009).

However, unlike most cement concrete modifiers, where the normal production process is barely unchanged, inclusion of elastomers into cement concrete has introduced some important techniques instead of the conventional production process which requires careful investigations for optimum results. According to Lech (2006), even though, polymeric substances have proved to be quite effective towards concrete metamorphism and adaptability, further research works are essential in order to make the improvements more efficient and reliable. In fact, the presence of medium of dispersion in liquid polymers, particularly synthetic and natural latexes (Mina *et al*., 2003), the fast setting characteristics of latexes, especially at temperatures above ambient level (Bala *et al*., 2009), the need for a coalesced latex-film as well as the function of latex as filler in capillaries and

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voids are typical issues which need to be examined for best possible results. In addition, compositional contents vary among latexes and these may of course affect not only the application techniques but also the overall performance of the modified phase. Therefore, factors, likely to affect the performance of the modified concrete during its production, should be explored so that proper actions relevant to the latex of choice are implemented.

The main objective of this work is to evaluate the effects of cement concrete-modification techniques with the hope of identifying most effective approach. The NRL was used in this investigation and this is mainly because of its renewable source and eco-friendly nature. Parameters involved in the study include mixing, setting time, water/cement ratio, latex dosage and curing regime. Effects of alternative techniques were investigated in each of the parameters considered. A series of control and NRL modified mixes were designed, produced, cured and tested through Differential Scanning Calorimetry (DSC) and compressive strength. Finally, observations were studied and adjustments as well as techniques, which yielded optimum results, were concisely reported.

MATERIALS AND METHODS

Materials and mix-design: Cement, aggregates, water and latex constitute the main materials used in this study. Ordinary Portland cement was used throughout and its chemical composition and physical properties are shown in Table 1. Crushed granite stones and naturally occurring river-washed quartz sand are used as coarse and fine aggregates respectively. The ASTM sieve No. 4 (4.75 mm) was considered as a demarcation between the two classes of aggregates. The sand has a fineness modulus of 2.4.

Fresh and concentrated natural rubber latexes were used as modifiers. A fresh latex; PB 260 was employed based on previous investigations in which this clone performed well in concrete (Bala *et al*., 2012). The concentrate however was of multiple clones. In order to convert coagulation, the latex was treated with 0.2% (by volume) low ammonia-tetramethythiuram disulfide/zinc oxide (LA-TZ). Latexes were supplied by Rubber Research Institute and Sime Darby Research Center, Segamat, Malaysia. Properties of the latexes were determined through chemical analysis, Scanning Electron Microscopy (SEM) and thermogravimetry analysis (TGA). While the chemical analyses of the latexes are shown in Table 2, the SEM and TGA are presented in Fig. 1 and 2, respectively.

Two concrete mixes were involved in this study. The mixed proportions of the materials, used in the two concrete mixes, are shown in Table 3. While 'Mix-design I' was designed for the general assessments, 'Mix-design II' was used for investigating further the impact of change in mix-proportion on the performance of the latex. On the other hand, the mixed proportions of the materials used in the production of the Hardened Cement Paste (HCP), cement-latex blend and cement mortars are shown in Table 4. In order to avoid excess water, the designed

Table 1: Chemical composition and physical properties of cement

	Values
Chemical composition (wt %)	
Silicon dioxide (SiO_2)	20.1
Aluminium oxide (Al_2O_3)	4.9
Ferric oxide (Fe_2O_3)	2.4
Calcium oxide (CaO)	65
Sulphur oxide (SO_3)	2.3
Magnesium oxide (MgO)	3.1
Physical property	
Surface area (Blair's) (m^2 kg^{-1})	290
Initial setting time (min)	105
Final setting time (min)	190
Soundness (mm)	8.7
Days in air at 2	
Insoluble residue (wt)	1.9%
Loss on ignition (wt)	2%
Lime saturated factor	0.85

Table 2: Chemical analyses of fresh and concentrated latexes

Property	TSC (%)	DRC (%)	NRC (%)	pH	VFA (%)	NH_3 (%)	MST(s)
Fresh Latex	27.20	25.39	1.81	10.24	0.038	0.37	-
Concentrated Latex	61.54	60.09	1.45	10.07	0.018	0.25	1227

TSC: Total solid content, VFA: Volatile fatty acid No., DRC: Dry rubber content, NH_3: Alkalinity, NRC: Non rubber contents, MST(s): Mechanical stability time (sec)

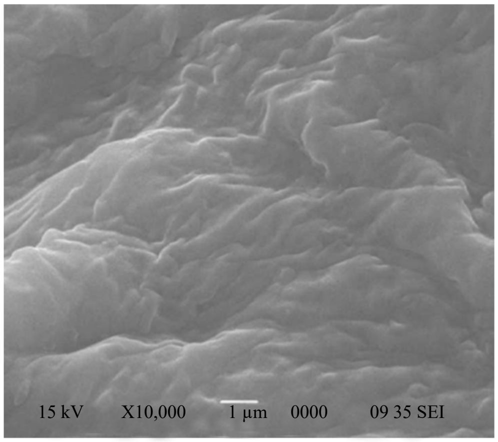

Fig. 1: Scanning electron microscopy of the latex-film

mixing water was generally reduced by 70 and 40% by volume of the intended latex for the fresh and concentrated latexes, respectively.

Specimen preparation: Materials were batched and mixed in accordance with BS 1881-125, 1986 (BS 1881:1986. Testing concrete-part 125). However, latex was added into the mixing water before adding the water content to the dry-mixed conglomerate. Attempts to add latex directly into the mix before and after adding the mixing water both yielded inconsistent mixes. Meanwhile, all mixes were laboratory-sized which do not entail transitional delay before placement.

Workability and setting time tests: Workability of mixes was assessed through consistency measurements of slump. Setting time was determined through cement paste

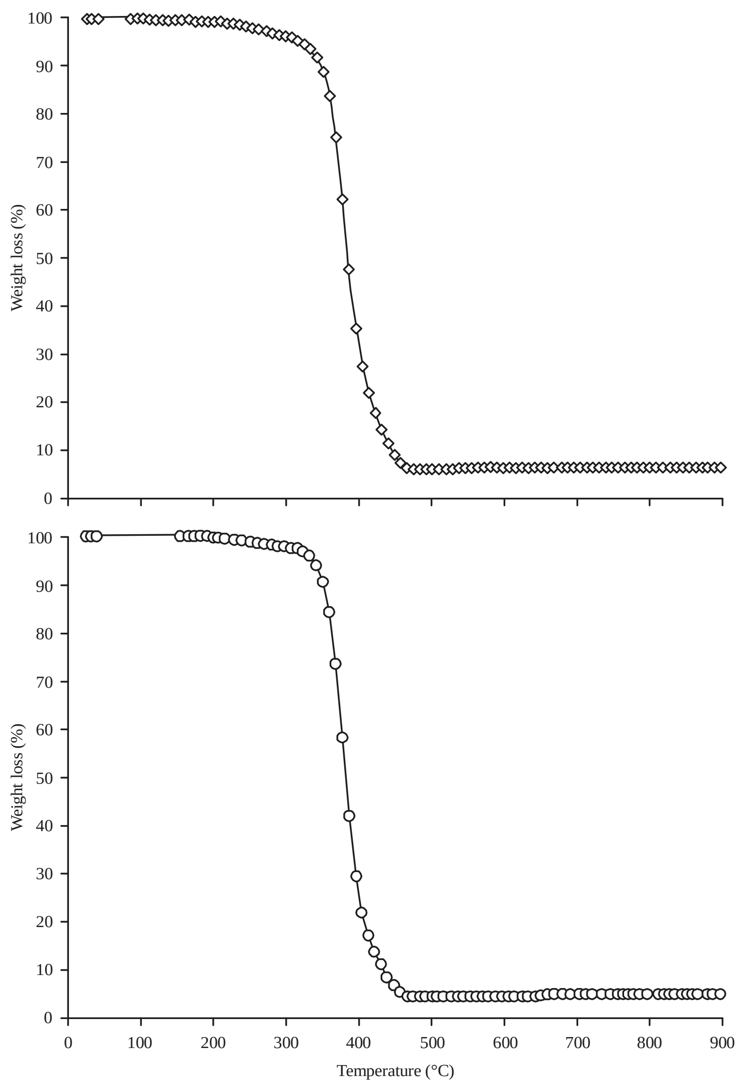

Fig. 2(a-b): TGA of the (a) Fresh latex (PB 260) and (b) Concentrated latex

Table 3: Mix-design: Concrete

	Quantity m^{-3} (kg)				
Mix design	Cement	Water	W/C	Fine aggregate	Coarse aggregate
1	425	230	0.54	780	915
II	435	190	0.44	705	1100

Table 4: Mix-design: Mortar

Specimen	Composition	Proportion
HCP	Cement+water	w/c ratio = 0.35
NRL-compounded	Latex film	-
NRL-concentrated	Latex film	-
NRL-deproteinized	Latex film	-
NRL RRIM 2015	Latex film	-
Cement-latex blend	Cement+latex	Latex/c ratio = 0.67
CWL	Cement+water+latex	1: 0.18:0.34
Control mortar	Cement+sand+water	1: 1.63:0.45
LMM 10 (%)	Cement+sand+water+latex	1: 1.63: 0.43:0.045
LMM 20 (%)	Cement+sand+water+latex	1: 1.63: 0.4:0.09

Fig. 3: Consignments of NRL-MC during air curing

mixed with normal mixing water and water containing the latex separately. In addition, the time observed for the initial setting time was related to the time lapse between mixing the concrete and in particular the physical behaviour of concretes mixed with different percentage of latexes.

Curing conditions: Full immersions of specimens in water as well as air curing systems were exercised, so that ideal moist condition for the cement hydration as well as coalescences of the hydrocarbon particles present in the latex were motivated accordingly. Thus, specimens were cured in accordance with JIS A1171:2000 (2M/5W/21A) (Japan Industrial Standards JIS1171:2000), which signifies 2 days in moist condition, 5 days in water at 20±3°C and 21 days in air at 20±3°C. Figure 3 presents a section of the specimens during air curing. However, the specified number of days in the JIS was further modified to 2M/3W/23A, 2M/7W/19A and 2M/9W/17A. The variations in the modification were aimed at evaluating the most favourable curing system for the NRL modified concrete phase.

Differential scanning calorimetry test: DSC was carried out using PERKIN ELMER DSC 7. However, prior to loading specimens were weighed on Mettler AE 166 and housed in a pressed aluminium pan. The heating rate and range were 20°C min^{-1} and 30-550°C, respectively. Nitrogen was also used as a purge gas at 20 mL min^{-1}.

Compressive strength test: The compressive strength test was in conformity with BS EN 12390-3, 2002 (BS EN 12390-3, 2002 Testing hardened concrete-part 3). Standard cubic moulds of internal nominal size 100 mm were employed. Average strength of three cubes was taken as the strength of each particular batch.

RESULTS AND DISCUSSION

Impact of mixing techniques: The techniques employed in the mixing process yielded different results. For instance, adding the materials into the mixer individually resulted in fast coalescing of the hydrocarbon substances as the latex was added into the mixing drum. The coalescing scenario was more rapid when the latex was added before adding the mixing water to the mix. In fact, adding the latex directly into the powdered cement was observed to promote instant coalescing of the hydrocarbons predominantly present in the latex making it completely difficult to achieve homogeneity in the overall mix. The fast coalescing behaviour is most critical where the concentrated latex was used and this is mainly due to reduction in the medium of suspension, normally present in the concentrated latex when compared with the fresh latex.

On the other hand, adding the latex first into the mixing water before adding the water content to the dry-mixed conglomerate yielded the best result in terms of homogeneity. However, dropping the latex into mixing water should be performed at relatively low height ($\leq$10 cm). Dropping the latex from greater heights promotes formation of air bubbles in the mixing water which, in turn, might give a rise to the development of higher porosity in the hardened phase of the modified concrete. In fact, gentle stirring of the mixing water was observed to be quite helpful after careful pouring of the latex content, as this action expels tiny air bubbles normally present in the latex.

Considering the fast coalescing nature of the elastomeric latex particularly when its medium of dispersion is drained through absorption by the surrounding cement powder, direct contact between cement and latex should be avoided. Indeed, adding first the intended latex into the mixing water allows for effective dispersion of the hydrocarbon substances not only in water but in concrete mix also. Eventually, the presence of latex in cement mixes was detected through DSC conducted on minute extracts from the hardened phases as discussed later in this study.

Influence of latex on workability and setting: The inclusion of latex into concrete mix was observed to cause significant changes in the workability. Figure 4 presents the results of the effect of latex on consistency of concrete measured immediately after mixing. It can be seen that there is a continuous increase in slump with increase in latex/water ratio. While the Normal Concrete (NC) produced the least slump, the Modified Concrete (MC) yielded higher slumps corresponding to the latex content added into the concrete mix. Indeed, the ease with which fresh latex modified concrete flows during mixing, placement and compaction is noticeably impressive when compared with that of the normal concrete. However, this positive effect was observed to cease at higher latex contents. In fact, at percentages such as 10% latex/water ratio or more which is ideal for durability applications (Bala and Ismail, 2012), the workability was observed to reduce mainly due to faster rate of coalescences associated with hydrocarbon substances.

The presence of dispersed latex particles in between aggregates was noticed to be the main cause of increased fluidity in the plastic state of the modified mix. Thus,

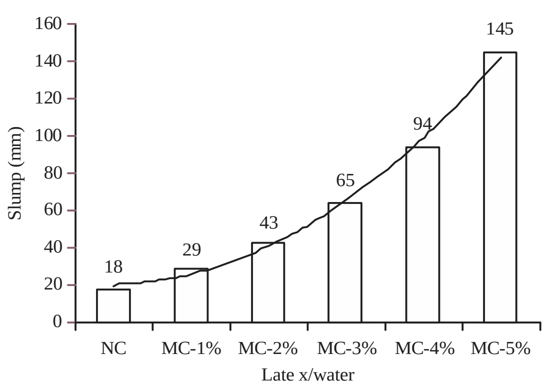

Fig. 4: Influence of latex content on workability

increase in the latex content further improves the ease with which aggregate particles slide over each other. However, this advantage gradually diminishes as the latex coalesces. Increase in the fluidity of fresh latex modified mix due to the presence of elastomeric substances in much harder aggregate particles has been described as 'ball bearing action' (Bala, 2012) but what was further observed in the present work was the rapid coalescences of the rubbery substances once the contents of the latex become relatively high.

Even though, a mix containing high dosage of latex can be assessed for slump but the fast coalescing behaviour of the hydrocarbon substances was observed to hinder complete effective casting and compaction of mixes particularly when several cubes are casted from a particular mix. Thus, workability of mixes containing high latex doses diminishes rapidly even before the usual setting time of cement.

Regarding the setting time, cement paste and the modified concrete containing low amount of latex depicted the usual initial setting time of about 45 min. However, modified mix containing high dosage of latex yielded different characteristics. Indeed observations revealed that for a period of about 35 min after mixing, depending upon the quantity of the latex added the mix gradually develops what may be described as initially weak chains of spongy chunks-clusters of cement coated aggregate particles interwoven by the fast setting latex. In fact, at about 1 h±5 min, the latex chains gained sufficient rigidity to deprive the mix from attaining the usual desired homogeneity when placed. Therefore, in order to avoid partial compaction due to relatively rigid-latex chains, production and handling processes such as mixing, transportation, placement and compaction of cement mixes containing high dosage of elastomeric latexes should be carried out at relatively shorter periods or best produced at the point of placement.

Optimization based on water/cement ratio: The results of 28 days compressive strength based on adjustments in water/cement ratio are shown in Fig. 5. The results were principally based on MC-3%. However, results of two mixes based on MC-5% were also included in order to ascertain whether a change in latex content will cause noticeable impact on the compressive strength due to variation in the w/c ratio.

The highest compressive strength of 35.56 N mm^{-2} was observed against 0.4 w/c ratio. Subsequent w/c ratio above 0.4 resulted in corresponding decreases in the compressive strength. Similar impact of decrease in compressive strength with increasing w/c ratio was observed in MC-5%. Therefore, the less the w/c ratio, the better it would be for strength development. In this

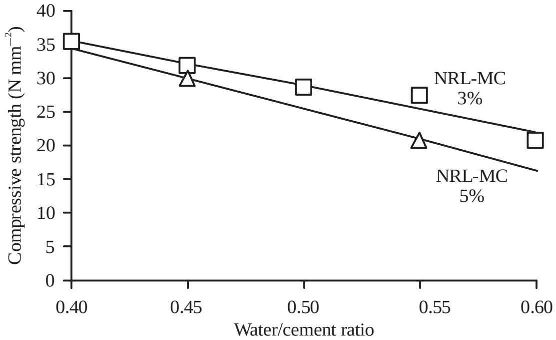

Fig. 5: Impact of water/cement ratio on NRL-MC

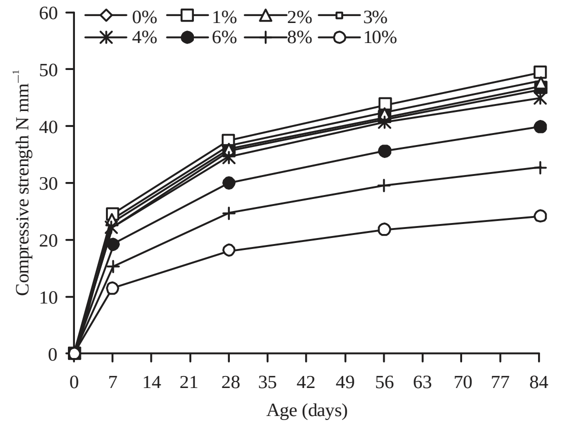

Fig. 6: Variation in compressive strength due to changes in latex content 4

respect, the ball bearing action of the latex could be of great advantage in the sense that the latex could aid consistency while maintaining low w/c ratio for the benefit of the strength improvements. In fact, the ball bearing action of hydrocarbon particles can be utilized by reducing the actual water/cement ratio for possible increase in strength especially in situations where mechanical properties are of optimal importance. Alternatively, employing the w/c ratio necessary for complete cement hydration only; 0.35 as recommended by Abraham’s law (Somayaji, 2001) while allowing workability to be achieved by the ball bearing action of hydrocarbon particles present in the latex could yield the best possible results on strength.

Considering strength variation in MC-5% due to change in w/c ratio, it could be seen that the increase in latex content has resulted in greater decrease in the compressive strength. Indeed, the steeper nature of the MC-5% graph in Fig. 4 has depicted 30.3% loss in strength between 0.45 and 0.55 w/c ratios as against 13.7% strength loss in MC-3% within the same interval. Thus, increase in w/c ratio with a corresponding increase in latex will cause a more negative influence on the strength.

Optimization based on latex dosage: Figure 6 presents the results of changes in compressive strength, due to the variation in latex content. There was a gradual increase in compressive strength with an increase in latex content until the optimum value was attained at about 3% latex/water ratio. However, further increase in latex beyond this content yielded a continuous decrease in compressive strength.

Generally, as fresh latex modified concrete loses its plasticity, the latex substances are entrapped in the capillaries and possibly in the voids of the hardened phase also. Thus, depending on the quantity of the latex present in the phase, the hydrocarbon substances may coalesce to form layers of films on cement oxides and aggregate particles. In fact, a major factor noticed to be responsible for the strength increase in elastomeric concrete is latex-film formation. According to Sakdapipanich (2007), the provided elastomeric concrete does not remain in constant moist condition, the latex coalesces into continuous films or membranes and these bind the cement hydrates together to form a monolithic network. Hence, while strength development in normal concrete is mainly a consequence of cement hydration, that of the latex modified concrete is usually a combination of both cement hydration and latex-film formation. To this respect, Neelamegam *et al*. (2000) suggested that the latex modification is mainly due to the latex film interpenetration into hydrated cement gel.

Meanwhile, where the quantity of the latex added into the mix is more than sufficient to fill in capillaries and possible voids in the hardened specimen, the excess latex tends to prevent the aggregate particles from coming closer, thereby creating weaker regions for earlier crack developments especially during compressive strength test. This could be the results of modifications beyond 3% latex/water ratio where compressive strengths of MC-4%, MC-6%, MC-8 and MC-10% depicted losses as shown in Fig. 6.

However, approximately 1.5% latex/water ratio was previously observed as the optimum content beyond which compressive strength dropped (Ismail *et al*., 2011). The difference in the two optimum values was the result of variation in the concentration of the hydrocarbon contents. While fresh latex was employed in the assessment of optimum content in the present study concentrated latex was applied in the former. Since concentrated latex contains hydrocarbon substances about the twice that contained in the fresh latex as already shown in Table 2, it implies that at least twice the amount of the latter should be added into the concrete mix for

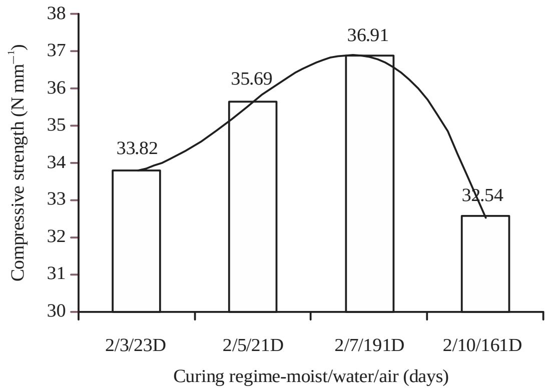

Fig. 7: Effect of curing regime on compressive strength

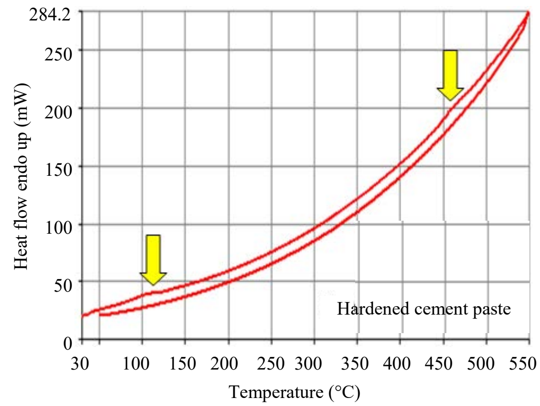

Fig. 8: Endothermic process of HCP

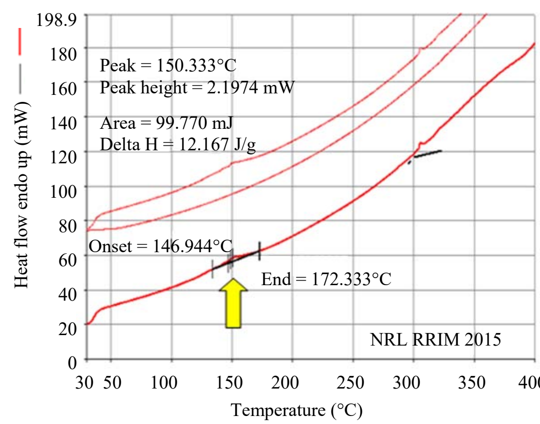

Fig. 9: Endothermic process of RRIM 2015

similar effectiveness caused by the former. From this, it could be deduced that in addition to the type of latex involved in the modification of concrete, concentration of the suspended particles in the liquid latex plays an important role also in determining the optimum content for maximum performance in the compressive strength of concrete.

Optimization based on curing regime: The results of the effect of curing regimes on the compressive strength are shown in Fig. 7. These results suggested 2M/7W/19A as the best curing method for NRL-MC. Shortfalls in the first two curing systems revealed the possibilities of retardation in strength development due to loss of water through evaporation during the early air drying process. Further increase in the number of days for specimens to remain in water beyond 2M/7W/19A has indicated a significant fall in the strength which signifies the lack of sufficient time for latex-film formation to fully develop.

The idea of the air curing was to allow for latex-film formation which is necessary for the development of additional strength over that arising from cement hydration. Thus, unlike NC where higher strength is achieved by wet curing alone, MC requires dry curing for optimum strength. Indeed, the result of the air curing process as manifested on the specimens resembles real conditions where most concretes are stripped off from work and allowed to develop strength in open atmosphere and not necessarily immersed in moisture.

According to Abdullah (2008), 2M/5W/21A is the best curing regime for modifications involving 10% latex/cement ratio. This value which is equivalent to about 20% latex/water ratio employed in the current study indicated the need for additional number of days for the higher latex content involved in the previous research to fully coalesce. In other words, differences in the two best curing regimes between the previous report and the findings in this work could be attributed to the fact that a longer air curing period is necessary in the former so that the higher latex dosage is fully de-moisturized before an effective latex-film formation could be achieved. Therefore, the provided mixing water does not escape through bleeding or evaporation, longer air curing period is necessary for optimum effectiveness in mixes containing relatively higher latex contents.

Differential scanning calorimetry: The results of the endothermic patterns of the individual principal materials; cement latex and mortar as well as co-matrices are illustrated in Fig. 8-12. Figure 8 shows the DSC of the HCP during heating as well as cooling processes. Except for the two shallow crests indicated by the two downward arrows, the pattern depicted smooth progress in the heat-absorbed and heat-released graphs during the heating and cooling processes, respectively. Considering the microstructural units in a typical cement matrix, the shallow crests at about 100 and 460°C could be related to its compositional contents. Indeed, the first crest could be the result of water vapour, capillary and the adsorbed and

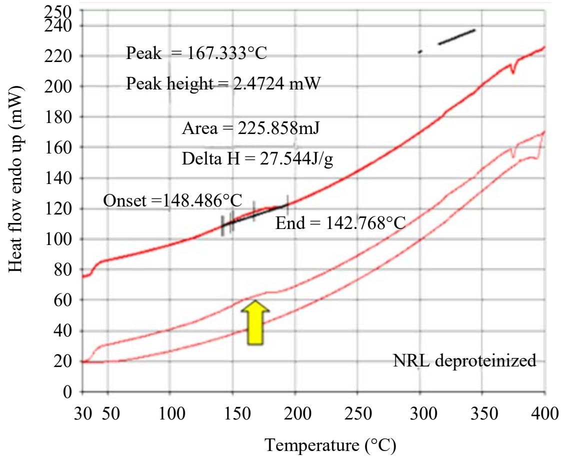

Fig. 10: Endothermic process of deproteinized latex

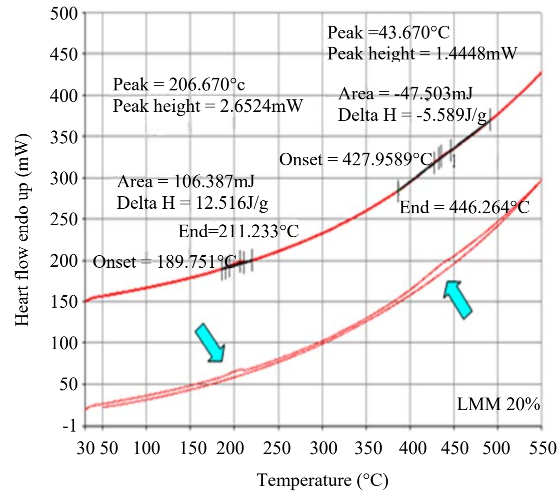

Fig. 12: Endothermic process of LMM-20%

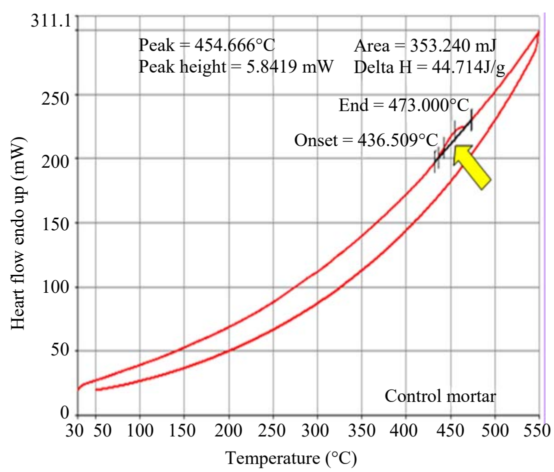

Fig. 11: Endothermic process of control mortar

interlayer moisture turning into steam. While the steam is expected to be expelled at a temperature of about 100°C, the chemically combined water requires much higher temperature of about 460°C for its expulsion. In fact, previous findings recorded escaped of a great deal of free and interlayer water at 105°C and appearance of explosive cracks at about 400°C (Khoury, 1992; Li *et al*., 2004).

The DSC results for the fresh and deproteinized latexes are shown in Fig. 9 and 10, respectively. The endothermic graphs of the two latexes yielded similar patterns with major noticeable crests appearing at temperatures between 100 and 200°C. Considering NRL RRIM 2015 for instance, the crest which suggests softening of the material occurred at a peak temperature of about 150.33°C with onset and end at 146.94 and 172.33°C, respectively. The deprotenized latex depicted its peak at a slightly higher temperature of about 167.33°C with the onset and end at 148.49 and 142.77°C, respectively.

These results depicted the behaviour of the two latexes under DSC tests. The slight difference between the two latexes was a result of the compositional differences shown in Table 2 specifically the TSC and DRC. The lower contents found in the fresh latex might have contributed to its faster flexibility when introduced to the endothermic process. Previously, earlier degradations were observed in non-concentrated latexes when introduced to elevated temperatures (Bala *et al*., 2009).

The control mortar which basically consists of HCP and sand depicted the DSC pattern shown in Fig. 11. In this case, the introduction of the sand into the HCP resulted in the elimination of the first crest previously observed in the HCP alone, an indication that the free moisture does not require specially generated heat for its escape. This is evident since the mortar is normally more porous than the HCP. Meanwhile, the upper crest which occurred at a peak of about 454.67°C obviously suggests expulsion of the chemically combined water which was previously observed in the HCP graph. Therefore, the minute DSC specimen has shown presence of the cement paste which generally coats and binds sand particles in the mortar.

Figure 12 presents the DSC of the latex modified mortar (LMM 20%). In this caption, the lower crest which appeared in NRL RRIM 2015 and NRL deproteinized resurfaced again. In addition, the upper crest which emerged from the endothermic processes of both cement and control mortar reappeared in LMM 20%. The appearances of the lower and upper crests signify the presence of the latex as well as HCP in the minute fragment of the LMM tested for DSC. In essence, the presence of latex in a minute specimen for DSC test which was obtained from the parent LMM suggests strongly the success of the mixing techniques employed in the mortar production which enables the latex to homogeneously appear in minute DSC test specimens.

CONCLUSIONS

Based on the parameters employed in this research, the salient conclusions on assessing extra production techniques necessary for achieving optimum performance in latex-modified concrete are drawn in the following:

- The best observed mixing technique most appropriate to the application of liquid latex into concrete involves introducing first the intended latex content into the mixing water at relatively low heights ($\leq$10 cm), followed by a careful stirring before adding the water to the mix. These allow for effective dispersion of the hydrocarbon substances as well as a means of efficient expulsion of air bubbles
- At low contents of latex ($\leq$10% latex/water ratio), the slump of a fresh mix increases with the increase in latex/water ratio. This advantage could be employed to improve performance in the compressive strength by lowering the actual water cement ratio so that workability is maintained through ball bearing actions of the latex particles
- In order to avoid partial compaction due to the formation of relatively rigid-latex chains, production and handling processes such as mixing, transportation, placement and compaction of cement mixes containing high dosage of elastomeric latexes should be carried out at relatively shorter periods or best produced at point of placement
- The less the w/c ratio, the higher the compressive strength in the latex-modified concrete. To this respect, care should be taken so that the content of the medium of dispersion does not add to the w/c ratio as this could lower the compressive strength. To avoid this, the estimated content of the medium of dispersion should be deducted from the calculated w/c ratio
- The roles of latexes of equal percentages but different concentrations of suspended substances on the compressive strength of latex-modified concrete vary significantly. Thus, for optimum performance, the individual concentrations of the suspended matters in the liquid latexes should be assessed and equally reflected in the concrete mix
- Increase in the latex contents of a fresh mix requires longer air curing periods for optimum strength in the hardened latex-modified concrete. This is mainly because the longer air curing period is necessary so that the higher latex dosage is fully de-moisturized before an effective latex-film formation could be achieved
- Presence of latex in a minute specimen indicated by DSC test reveals effective dispersion of the hydrocarbon substances in the parent LMM mix. Thus, the mixing techniques employed in the production of the mortar have contributed to the achievement of homogeneous mix

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