스티렌 부타디엔 고무 라텍스를 첨가한 시멘트 페이스트의 내충격성 평가

Evaluation of the Impact Resistance of Hardened Cement Pastes by Adding Styrene-Butadiene Rubber Latex

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Abstract

In this article, the effect of latex polymer modification on improving the impact resistance of cement pastes has been investigated. The control cement mixture was proposed with water-cement ratio of 0.5. Based on that, the cement pastes were modified by partially substituting water content with Styrene-Butadiene Rubber (SBR) latex. The mixture ratios were prepared by adjusting the various SBR latex dosages from 5 wt % to 20 wt % of water content. The specimens of modified pastes in the hardened state were tested by Charpy impact experiment and compared to the pure ones after 7, 14, 28, 45, and 60 days of curing. The observation results showed that there is a remarkable improvement in the impact resistance of modified cement pastes. Further, the optimal SBR latex dosage of 10% was proposed.

Key words : Impact Resistance, Charpy Experiment, Styrene-Butadiene Rubber Latex, Polymer Modified Cement

요 지

본 연구의 목적은 시멘트 페이스트의 내충격성에 라텍스 폴리머의 첨가량이 미치는 영향을 조사했다. 시멘트 혼합물은 물 시멘트 비 0.5로 제작 되었다. 시멘트 페이스트는 스티렌-부타디엔 고무 (SBR) 라텍스로 부분적으로 물을 대체하여 제작되었다. 혼합비는 SBR 라텍스 투입량 5%에서 20%의 중량비로 물을 조절하여 제조 하였다. 경화 상태의 SBR 개질 페이스트의 시편은 샤르피 충격 실험에 의해 시험되었고 양생 7일, 14일, 28일, 45일 및 60일 후에 일반 시멘트 시편과 내충격성이 비교되었다. 실험결과는 SBR 개질 시멘트 페이스트의 내충격성이 현저하게 개선되었음을 보여 주었다. 또한, 내충격성 향상을 위해 SBR 라텍스 용량 10 %가 최적임을 보였다.

핵심용어 : 내충격성, 샤르피 실험, 스티렌-부타디엔 고무, 폴리머 개질 시멘트

1. Introduction

Concrete is the most dominant material in general construction fields, particularly in the transport infrastructure. It is difficult to find out any material that can completely

replace its role in nowadays or near future. However, the principal disadvantage of conventional concrete is brittleness (Brandt, 2009), consequently, the improvement of this property has been researched. The use of polymer in concrete has been recognized to improve the mechanical and physical

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properties of concrete such as compressive strength, flexural and tensile strength as well as good performance in enhancing durability, anti-corrosive, and low permeability. Generally, there are three types of concrete that made by adding polymer: polymer impregnated concrete (PIC), polymer concrete (PC), and polymer modified concrete (PMC) (ACI 548.1R, 2009). Among them, polymer modified concrete have been considered interesting materials because the process to use them is very similar to the ordinary ones. The polymer plays a role as the admixture in the concrete mixture, a part of cement binder (less than 20% by weight) was replaced by an adequate amount of polymer for remaining the cost (Fowler, 1999). According to the report of ACI Committee (548.3R, 2009), only five major commercial polymers were widely used for modification of cementitious mixtures and the prices were arranged from highest to lowest as the following: Acrylic Polymer (AP), Styrene Acrylic (SA), Styrene-Butadiene Rubber (SBR), Ethylene Vinyl Acetate (EVA), and Polyvinyl Acetate (PVAc). Each polymer maybe exists in either dispersible (liquid) form or re-dispersible (powdery) form. They have strengths as well as weaknesses under certain conditions and imparts different properties when used as an additive to or modifier of cement mixtures. Also, for each type of latex, particularly copolymer latexes, many variations give different properties to hardened mortar and concrete. If the appropriate polymer is selected and the dosages are reasonably proposed, it helps to improve the concrete properties significantly. Latex is the form of a colloidal suspension polymer in water, for instance, Styrene-Butadiene Rubber (SBR), which is the copolymerized product of two monomers: Styrene and Butadiene, have commonly used in the construction field (Ohama, 1995).

There are many studies mentioned in the influence of SBR latex, which is used as an admixture for the modified mortar and concrete. Shaker et al. (1997) researched the durability of Styrene-Butadiene rubber latex modified concrete (SBR-LMC). The results showed the improvement of water penetration, absorption, and sorptivity properties; in addition, the abrasion resistance, as well as the corrosion resistance in chloride environment were higher than conventional concrete. Using scanning electron microscope (SEM) method, they concluded latex modified concrete have a dense microstructure and excellent bonding among the internal elements. Rossignolo et al. (2002, 2004) proposed using SBR latex for lightweight aggregate concrete (LWAC). The modified LWAC provide with significant improvement in the tensile and flexural strengths; the better corrosion

resistance, effective protection against the attack of acid, and the water absorption decrease when compared to unmodified LWAC. Huang et al. (2010) investigated the effect of the SBR latex on polymer-modified pervious concrete (PMPC) by adding fiber and natural sand with the various dimension. The results showed that if latex and sand were both added, the porosity and permeability would decrease, while the compressive strength would improve; and if the latex was only added, the split tensile strength would increase. Besides, the flexural strength and anti-freezing ability of PMPC were improved when the SBR latex dosages were between 10% and 15% through the research of Xiao et al. (2018). Li et al. (2010) indicated that the optimal SBR latex content was 5% by weight to improve the flexural strength and the pore distribution of the steel fiber-reinforced concretes, with the binder of the mixture was used include of cement, silica fume and fly ash. Bhikshma et al. (2010) observed mechanical properties and permeability characteristics of five various grades of concrete from M20 to M60 with polymer dosages from 5% to 10% by the weight of cement for each grade. In general, the overall efficiency of the concrete is improved with the addition of SBR latex, on all the grades were tested. However, the affecting of polymer on the performance of Normal Strength Concrete (NSC) is more significant than High Strength Concrete (HSC). Only considering on HSC was designed for C50/C60, Dogan and Bideci (2016) determined that the replacement of SBR latex for cement by 1% weight will lead to the positive efficiency for the strength characteristics.

On the other hand, Bureau et al. (2001) carried out three-point bending and compression tests on Styrene-Butadiene Rubber latex modified mortars (SBR-LMM) under strain controlling to get the softening branch of the stress-strain curve. The results show that initial stiffness and the maximum stress decrease when using high polymer dosage, the optimal ratio of the solid polymer concentration to cement about 7.5-10%. Barluenga and Hernandez-Olivares (2004) researched on the correlations among dosage parameters, the variation of the physical as well as the mechanical characteristic of SBR-LMM in the fresh and hardened states, therefore, the approval of linear approximations will depend on the ratio of water-to-cement and percentage of latex. On the other aspect, dynamic modulus and the dielectric loss were evaluated based on dynamic compression tests. The properties of the cement mortar can be estimated by using nondestructive test methods was a suggestion. Wang et al. (2005) investigated the flexural and compressive strength

and apparent bulk density of SBR-LMM under different curing conditions. They can be approximated by a linear relationship and slightly increase when SBR/cement ratio is less than 10%. The bonding structure between the polymer and hydrate cement membrane fully develops until P/C grade is 10%. The properties of SBR-LMM were influenced by the polymer membrane, the cement hydrates, and the bonding structure between the organic and inorganic phases. Yang et al. (2009) evaluated the chloride permeability and microstructure of SBR-LMM by using physical testing methods. The measurements demonstrate that the combination of SBR latex improved the chloride permeability, to alter the morphology and microstructure of the mortar. In addition, the combination of SBR latex in cement mortar slightly reduce Portlandite and carbonation content. And, the polyester fiber was blended inside SBR-LMM to overcome the high brittleness of ordinary mortar. Deng et al. (2016) observed polymer membrane can activate polyester fiber and the cement paste for tight connecting and reducing the micro and macro defects in cement mortar. The compound reinforcement enhanced the results of modification in workability, mechanical performance, and durability. Hwang and Ko (2008) used or recycled waste concrete or artificial marble waste for the role of the fine aggregate. As a result, the presence of SBR gave the increase of the air content as well as the decreasing of the compressive strength.

Meanwhile, the cement performs as the binder and is also the weakest phase in the structure of the concrete when be subjected to loads and external environment agents, it decides the strength of concrete distinctly. There have been some previous studies on the properties of SBR latex-modified paste (SBR-LMP). Wang et al. (2006) used a series of microstructural analyses, including differential scanning calorimetry (DSC) analysis, X-ray diffraction (XRD), and ^{27}Al and ^{29}Si solid-state nuclear magnetic resonance (NMR) spectrum method to research the effect of SBR on cement hydrates $\text{Ca}(\text{OH})_2$, ettringite, C_4AH_{13} , calcium-silicate-hydrate (C-S-H gel) and the degree of cement hydration by means of several measure methods. Yao and Ge (2012) evaluated the influence of different contents of SBR (0%, 5%, 10%, 15%, and 20% of cement) on the compressive strength, flexural strength, elastic modulus, and anti-permeability of the paste, mortar, and concrete with the same water-to-cement ratio. Experimental results showed that their properties changed in the same way with the combination of the SBR latex. Wang et al. (2011) established the correlation between the dynamic elastic modulus of mortars with the indentation modulus of cement pastes, the mortar

strengths with the hardness of the cement pastes based on nanoindentation technique and standard methods with the change of SBR latex content. Accordingly, SBR latex/cement ratio of 8–10% were found as the optimal polymer content in practical applications.

For enhancing the safety of the structure, the mechanical properties of material should be interested. In particular, for brittle materials like concrete, the impact strength (toughness) is indispensable parameter because of its sensibility and vulnerability. The brittle material is not much deformed during the breaking process and only low energy absorption. The impact test is the measurement of the material's response to sudden collisions or strong impulses. Therein, the Charpy testing has been seen as the most popular inspection methods, which is a fast, easy and economical to determine the result (Dowling, 2013). The substance of this experiment is a dynamic three-point bending test. The broken specimen takes place under fast loading conditions to determine energy absorbed from the material failure. Currently, this method is used in many industries to evaluate the toughness of materials; It has been conducted and standardized by ASTM and ISO for metals testing (ISO 148, 2016; ASTM E23, 2018) and plastics testing (ISO 179, 2010; ASTM D6110, 2018). Additionally, this experiment was applied on polymers (Francois and Pineau, 2002) or there were many studies using the Charpy impact test for composite materials testing (Hufenbach et al., 2008; Ghasemnejad et al., 2010; Hong et al., 2013). Meanwhile, the hardened cement pastes is a common material in construction, its impact resistance was only evaluated in the study by Nguyen and Kim (2018). Therefore, the major concern of the current study is to investigate the influence of SBR latex on the impact resistance of cement pastes by Charpy impact experimental. The optimal dosages of SBR latex are proposed with the purpose of keeping the compressive strength at 28 days stay unchanged.

2. Specimen Preparation and Testing Methods

2.1 Materials

In this research, the ordinary Portland cement is used. Styrene-Butadiene Rubber (SBR) latex in emulsion form (a commercial polymer product) has basic properties as presented in Table 1. Tap water is employed for all of mixtures and during the process of curing.

Table 1. Physical Parameters of Styrene-Butadiene Rubber Latex

Properties	Description
Appearance	white
Total solid content [TSC, (%)]	47
pH value	9-11
Density (kg/m^3)	1090
Viscosity (cps)	Below 500
Average Particle Size (Angstroms)	1600
Glass Transition Temperatures [T_g , ($^{\circ}\text{C}$)]	5
Minimum Film-formation Temperature [MFFT, ($^{\circ}\text{C}$)]	5

2.2 Mix Proportions

The intention of mixture proportion used in this study is to have the same compressive strength at 28 days for the hardened cement pastes with different SBR Latex dosage. Therefore, the water contents in mixture proportion decrease by the increase of SBR Latex contents. Based on trial mixtures, the amount of reduction water contents was determined by Eq. (1) and Eq. (2) for the hardened cement paste to have the same compressive strength at 28 days.

$$P = a W_P \quad (1)$$

$$W_A = W_P - 2P \quad (2)$$

Where, a (%) is the ratio of SBR latex weight, P to the weight of water, W_P in the control cement pastes mixture, so called as “latex ratio” in this study. Using Eq. (2), the weight of water, W_A for the latex modified cement paste is calculated. In this study, W_P/C ratio of 0.5 is used. The cement pastes with SBR were prepared with various latex ratios from 0% to 20%. The mixture proportion detailing

of eight pastes are summarized in Table 2.

2.3 Experiment Process and Method

The specimens for Charpy experiment were proposed as bar shape, with the width and height of 10(+/-)5mm and the length of 50(+/-)1mm as shown in Fig. 1 (a). The cube specimens (50x50x50mm) for the compressive strength tests were prepared.

The cement pastes were blended by the apparatus at the control mode based on ASTM C305 (2014). The fresh pastes were cast in molds. After 24hours, the hardened specimens were de-molded and immersed into the water tank until the required time for experiments. Casting and storage processes were carried out in accordance with the technical requirement of ASTM C192/C192M (2016) and ASTM C511 (2013), respectively.

The compressive strength of hardened cement pastes with SBR was measured following as ASTM C109/C109M (2016) at the curing time of 28 days. The average value of the compressive strengths for six specimens was reported.

Fig. 1. The Dimension of a Specimen for Charpy Impact Test (a) and schematic of Charpy hammer, cement specimen and anvils (b) (units: mm)

Table 2. Details of Mix Proportions of Modified Cement Pastes

Description	Cement pastes mixtures [kg/m^3]							
Latex ratio [a , (%)]	0	5	8	10	12	15	18	20
Cement (C)	1221	1263	1290	1308	1327	1356	1387	1408
SBR Latex (P)	0	32	51	65	80	102	125	141
Water content (W_A)	611	568	541	523	504	475	444	422
Solid content in latex (P_S)	0	15	24	31	38	48	59	66
Water content in latex (P_W)	0	17	27	34	42	54	66	75
P_S/C [%]	0	1.18	1.88	2.35	2.82	3.53	4.23	4.7
$(W_A + P_W)/C$	0.5	0.46	0.44	0.43	0.41	0.39	0.37	0.35
Compressive strength at 28 days [MPa]	49.4	45.78	46.4	47.6	46.53	45.33	44.51	46.84

Meanwhile, the impact resistance was measured at the curing time of 7days, 14days, 28days, 45days and 60days. The Charpy experiments were conducted according to ASTM D6110 (2018). A machine having the hammer weight of 0.7kg and the impact speed of 2.92m/s at the hitting point was used for the Charpy experiments as shown in Fig. 2. The V-notch with the depth of 2+0.3mm was created to induce the failure surface at the middle of specimens as shown in Fig. 1 (a).

The two types of setting for anvil distance, L of 20mm and 40mm were used to introduce shear failure and flexural failure of the specimens, respectively. The impact resistance is determined by dividing the used energy for breaking specimen by the area of failure surface at the notch of specimen. The average value of Charpy results of 20 specimens was reported for each cement paste mixture and curing time.

Fig. 2. The Charpy Impact Instrument

3. Results and Discussion

The results from the compressive strength test of cement pastes with SBR for the different latex ratios were presented in Table 2. It indicates that the compressive strengths at 28 days for all SBR modified specimens show similar values as expected. The impact resistances of cement pastes with SBR with respect to the latex ratio were shown in Fig. 3 and Fig. 4 for the different anvil distance of 40mm and 20mm respectively.

In Fig. 3 for the observation for Charpy experiments with the anvil distance of 40mm, the impact resistances of cement pastes with SBR having the latex ratio from 5% to 18% were not shown large differences. Compared to the control specimen, these impact resistance increased by 5% to 10% depending on the curing time and latex ratio.

Fig. 3. Effect of SBR Latex Ratio to the Impact Resistance of Cement Pastes, L=40 mm

In Fig. 4, it was shown that the impact resistance of cement pastes with SBR increased in accordance with the increase of the latex ratio up to 10%. After the latex ratio over 10%, the impact resistance decreased with the increase of latex ratio. The most improvement of the impact resistance was approximately 70% for the cement paste with latex ratio of 10% at the curing time of 7 days. The impact resistance of cement pastes with SBR was improved efficiently. It was also consistent with the research of Ohama et al. (1964).

As the impact force to make shear failure is higher than that to make flexural failure, the difference of impact resistance for cement pastes with respect to latex ratio is more distinguished for the Charpy experiment observations with the anvil distance of 20mm in Fig. 4 than those with the anvil distance of 40mm in Fig. 3.

Fig. 4. Effect of SBR Latex Ratio to the Impact Resistance of Cement Pastes, L=20 mm

Fig. 5 presents the development of impact resistance of cement pastes with SBR according to the curing time. The impact resistance of cement pastes without SBR increased 50% for 60 days. The amount of impact resistance increase

is 9% for the cement pastes with latex ratio of 5% and 8%.

After 28 days, the increase rate of impact resistance for all specimens decreased. The amounts of impact resistance increase for all specimens are 2% and 3% respectively at 45 days and 60 days compared to that at 28 days.

As shown in Fig. 5, the cement pastes with latex ratio of 10% attain the highest impact resistance from 7 day to 60 day of curing time.

Fig. 5. Impact Resistance of Cement Pastes with Different Curing Time, L=20 mm

Consequently, the latex modified cement pastes are tougher than the unmodified cement pastes because SBR latex makes the connection between the cement particles become stronger (Ohama, 1995). As the impact resistance is related to toughness of materials, the impact resistance of cement pastes can be improved by adding SBR latex. The optimal dosage of 10% latex ratio is proposed from the experiments.

4. Conclusion

This research concentrated on the effective utilization of Styrene-Butadiene Rubber (SBR) latex to improve the impact resistance of the hardened cement pastes. Conclusions based on the observations are as follows:

- (1) The SBR latex additive help to enhance the impact resistance of cement pastes.
- (2) The use of SBR latex caused the decrease of the compressive strength.
- (3) The observation of this study indicates that latex ratio of 10% is the optimum latex ratio to give the highest impact resistance of the latex modified cement pastes.

Moreover, this research supports the effectivity of Charpy experiment for quasi-brittle material to measure the impact

resistance. It might be possible to estimate the toughness of hardened cement pastes.

Acknowledgments

본 연구결과물은 2018년도 광득건설의 연구비 지원에 의한 것임.

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Received	November 5, 2018
Revised	November 6, 2018
Accepted	November 12, 2018