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Research Article

Synergistic Effect of Latex Powder and Rubber on the Properties of Oil Well Cement-Based Composites

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The brittleness and the poor resistance to external load of oil well cement impede the development of oil and gas wells. To overcome these deficiencies, latex powder or rubber and their hybrid combinations were used to modify the oil well cement. The conventional properties, mechanical properties, and scanning electron microscopy (SEM) images of the modified cement were analyzed. In comparison with latex powder-incorporated cement and rubber-incorporated cement, a significant improvement of fluid loss, flexural strength, impact strength, and elasticity of the cement slurry was observed when using the hybrid combinations of 3 wt.% latex powder and 2 wt.% rubber, although this synergistic effect was not remarkable on the compressive strength and the thickening time. These evidences arose from the synergism between latex powder and rubber leading to the formation of a three-dimensional network structure and a flexible structure which subsequently improved the elasticity and toughness of cement stone. The improved elastic matrix has a buffering effect on external impact when the cement stone is subjected to an external load.

1. Introduction

Cementing is to inject cement slurry in between the annular of casing and the formation, and the cement sheath is formed after curing of cement slurry. The cement sheath has the main functions of suspending and protecting the casing, reducing and delaying the effect of formation on casing, improving the stress state of casing, and prolonging the service life of casing [1, 2]. Although Portland cement is a good material and achieves high compressive strength at low cost, its brittleness has been evidenced [3]. During the development of oil and gas wells, the cement sheath is subjected to various loads including the change of internal pressure and temperature and so on. Changes of various loads often lead to sealing failure, sustaining casing pressure, fluid channeling, and even wells scrapped [4]. The sealing ability of cement sheath is not only directly related to the effective implementation of drilling, completion, development, EOR, and other measures [5], but it also relies on the overall economic benefits of oilfield exploration and development.

In order to achieve long-term integrity of the cement sheath, cement slurry should possess good construction performances, favorable mechanical properties, and sufficient flexibility [6].

Basically, the three main varieties of flexible materials used to improve the mechanical properties of oil well cement include fiber, latex, and rubber. As flexible materials, the various types of fibers are polypropylene fiber, carbon fiber, glass fiber, and asbestos fiber [3–7]. Fracture of cement stone occurs as a result of tensile stress of fiber which subsequently transfers the substrate through the adhesive force aims at limiting the expansion to fracture. Moreover, unavoidable fracture development leads to the stretching, the pulling out, or the failure of fiber as a consequence of consuming huge amount of energy which subsequently results in a brittle cementing material [8]. Additionally, the difficulty of fiber to be dispersed and its easiness to reunite in the cement slurry constitute another major drawback [9].

Latex has been widely used in oil well cement as a performance improver in the following aspects [10–13]:

(i) It can improve the antichanneling ability of cement slurry

(ii) It can decrease the permeability of cement stone

(iii) It is used in cement slurry to demonstrate good flexural strength and impact strength necessary to reduce probability of cement stone damaged during subsequent operations

(iv) It has been used to provide sufficient elasticity necessary to guarantee the integrity of the internal structure of cement stone

(v) Simultaneously, it can improve the cementing quality in the first and second interface

Rubber is an elastic material with smaller size particles, distributed uniformly and used to fill any void within the cement particles in the slurry. Moreover, the transfer medium of impact reflected by the formation of skeleton with numerous particles and gels stacking within the cement stone occurs [14–16]. Additionally, after transferring the force to flexible rubber used in cement particle filling, the elastic flexible rubber produces a buffering effect which absorbs part of the energy. Hence, it improves the ability of resisting external force damage [17, 18]. The application of flexible rubber in cement slurry can improve the internal deficiencies of cement paste, restrain the generation and expansion of microfractures, and form the structural center of energy absorption [19, 20].

In order to enhance the performance of oil well cement, many research studies based on using a single flexible material have been well evidenced, but reports on the application of a hybrid combination of polymer flexible materials in cement slurry are not well documented to date. In an attempt to develop excellent cement slurry for the cementing process, a hybrid combination of flexible materials composed of latex powder-rubber was used in the cement slurry. The synergistic effect related to their representative functions was studied. The research results provide reference for developing a flexible cement slurry system.

2. Materials and Methods

2.1. Materials. The cementing materials obtained from Gezhouba Special Cement Co., Ltd, China, were of conventional class G oil well cement. Latex powder and materials including filtration reducer, dispersant, and defoamer were procured from Jingzhou Jiahua Technology Co., Ltd, China. The enhancer and retarder were produced in the laboratory. The average particle size of the latex powder was about 160 μm. The filtration reducer was an anionic polymer and made from acrylamide and its derivatives, which was used to reduce the water loss of cement slurry. The dispersant was sulfonated acetone-formaldehyde condensate, and its function was to improve the fluidity of cement paste. The defoamer was incorporated in order to eliminate foam in cement slurry and it was mainly composed of emulsified silicone oil. The enhancer was made up of microsilica, and it could enhance the strength of cement sample. The retarder was a mixture of tartaric acid and borate, and it was added aimed at adjusting the thickening time of cement slurry. Rubber was obtained from Guangzhou Best New Materials Co., Ltd. (China), and it was granular polymer material. Rubber was hydrophically modified by 3-methacryloxypropyltrimethoxysilane before its use in this work. In all experiments, tap water was used as the aqueous solution.

2.2. Sample Preparation. Preparation and curing of oil well cement were conducted according to the Chinese standard test protocol GB/T 19139-2012. According to the specific compositions of cement slurry shown in Table 1, cement, filtrate reducer, dispersant, enhancer, latex powder, and rubber were first mixed as dry powder. Second, a certain amount of tap water was taken and the retarder and defoamer were dissolved in water to form a mixed water solution. Then, the mixed water solution was poured into the mixing cup and was stirred using the constant speed agitator (TG-3060A, Shenyang Taige Petroleum Instrument & Equipment Co., Ltd.) at a speed of 4000 ± 200 r/min, and the mixed dry powder was added into mixed water solution at this speed within 15 s. Consecutively, the cement slurry was stirred for $35\,\text{s} \pm 1\,\text{s}$ at the speed of 12000 ± 500 r/min. Then, the cement sample was prepared for the experiment.

2.3. Testing Procedures. Oil well cement slurries were tested according to the Chinese standard test protocol GB/T 19139-2012. A constant speed agitator was used for the preparation of cement slurry. After curing for 20 min at 90°C and 0.1 MPa, the rheological properties of cement slurry were tested using a rheometer (OFITE900, OFITE, USA). A pressurized consistometer (TG-8040DA, Shenyang Taige Oil Equipment CO., Ltd, China) was used to measure the thickening time at 90°C and 45 MPa. HTHP fluid losses were taken using a HPHT Filter Press (TG-71, Shenyang Taige Oil Equipment CO., Ltd, China) at 90°C and 6.9 MPa for 30 min.

In order to examine the mechanical properties of the slurry, all the samples were cured at 90°C and 21 MPa. The cured samples ($50.8\,\text{mm} \times 50.8\,\text{mm} \times 50.8\,\text{mm}$) were used to examine their compressive strength at a constant loading rate of 72 kN/min. The cured rectangular stone ($40\,\text{mm} \times 40\,\text{mm} \times 160\,\text{mm}$) was used to measure flexural strength (3-point bending). Pendulum impact tester (XJJY-50, Chengdeshi Shipeng Detection Equipment Co., Ltd., China) was used to assess the impact strength of samples ($10\,\text{mm} \times 15\,\text{mm} \times 120\,\text{mm}$). Regarding the Chinese standard test protocol GB/T 50266-2013, the uniaxial stress-strain curves were determined using a universal testing machine (HY-20080, Shanghai Hengyi Precision Instrument Co., Ltd., China) at a constant loading rate of 2 kN/min after curing for 28 days.

The microstructure of cement stone was observed using a scanning electron microscope (SEM) (SU 8010, HITACHI, Japan).

Table 1: Specific compositions of cement slurry.

Sample number	Cement (wt.%)	Water (wt.%)	Filtrate reducer (wt.%)	Enhancer (wt.%)	Dispersant (wt.%)	Retarder (wt.%)	Defoamer (wt.%)	Latex powder (wt.%)	Rubber (wt.%)
P	100	44	2.5	2	0.5	0.4	0.5	0	0
L1	100	44	2.5	2	0.5	0.4	0.5	1	0
L2	100	44	2.5	2	0.5	0.4	0.5	2	0
L3	100	44	2.5	2	0.5	0.4	0.5	3	0
L4	100	44	2.5	2	0.5	0.4	0.5	4	0
R1	100	44	2.5	2	0.5	0.4	0.5	0	1
R2	100	44	2.5	2	0.5	0.4	0.5	0	2
R3	100	44	2.5	2	0.5	0.4	0.5	0	3
R4	100	44	2.5	2	0.5	0.4	0.5	0	4
LR1	100	44	2.5	2	0.5	0.4	0.5	3	2
LR2	100	44	2.5	2	0.8	0.4	0.5	3	2

3. Results and Discussion

3.1. *Effect of Latex Powder Content on the Performances of Cement Slurry*

3.1.1. Effect of Latex Powder Content on Conventional Properties. The conventional properties of cement slurry mainly include rheology, thickening time, and fluid loss. Moreover, the rheological property and thickening time are the safety standards of cementing construction [21, 22]. The first one affects the pump safety of cement slurry while the second one determines the delivery cycle safety of cement slurry during pumping. On the other hand, fluid loss intimately affects the quality of cementing.

The conventional properties of cement slurry with various latex powder contents ranging from 0 to 4 wt.% were evaluated, and the experimental results are shown in Table 2 and Figures 1 and 2. With reference to Table 2, it is clearly evidenced that the latex powder has an effect on the rheology of cement paste. With increasing latex powder dosage, the fluidity of cement slurry becomes worse. Hence, an appropriate amount of dispersant should be added to adjust the rheological property of latex-incorporated cement slurry. Nevertheless, there is no obvious dependence of thickening time on the latex powder content, and the cement slurry with the content of 4 wt.% latex powder can meet the construction requirements as indicated in Figure 1. The latex powder can effectively reduce the fluid losses of cement slurry as presented in Figure 2. This observation arose from the fact that the latex powder formed a softening film at a certain temperature as a consequence of covering the cake pore as well as preventing the filtration and reducing fluid loss.

Table 2: Dependence of latex powder content on rheological properties of cement slurry.

Sample number	Latex content (wt.%)	Φ_{600}	Φ_{300}	Φ_{200}	Φ_{100}	Φ_6	Φ_3
P	0	283	187	132	73	7	3
L1	1	300+	219	157	88	7	4
L2	2	300+	232	172	95	9	5
L3	3	300+	289	233	136	10	7
L4	4	300+	300+	251	152	14	10

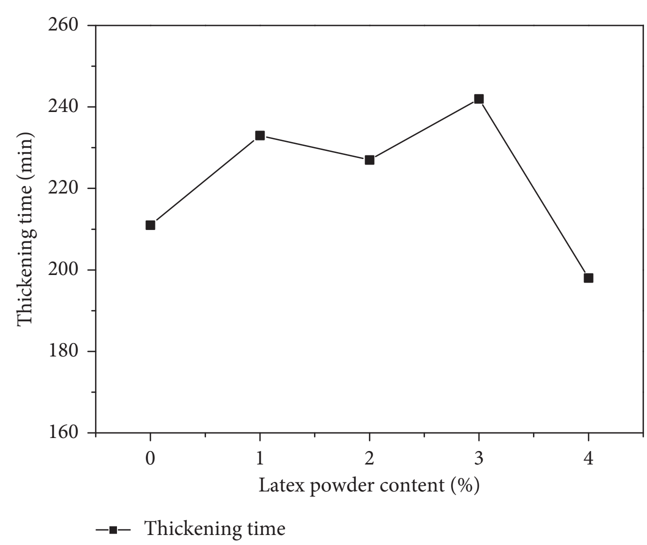

Figure 1: Dependence of latex powder content on thickening time of cement slurry.

3.1.2. Effect of Latex Powder Content on Mechanical Properties. In order to effectively seal the annulus, the cement stone must possess good mechanical properties. The compressive strength of cement paste represents the ability to maintain the integrity of cement paste under compressive stress, which is one of the most important evaluation criterion for cementing. It also reflects the maximum stress of cement paste destroyed by uniform velocity compressive stress on the contact surface of a unit [23]. The flexural strength stands for the ability of cement stone to withstand external shear which indirectly characterizes the toughness of cement [24]. Another relevant property of the cement slurry is the impact strength, which is the energy consumed by the sample after an impact. The impact strength is an indicator of the cement stone's ability to resist impact, and it is also used to assess the

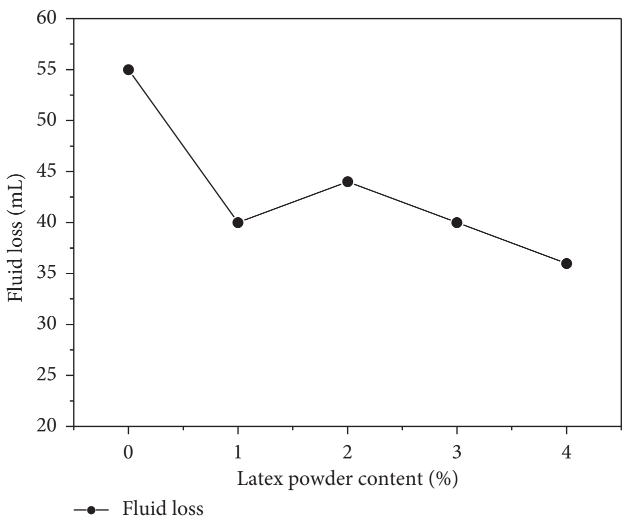

Figure 2: Dependence of latex powder content on fluid loss of cement slurry.

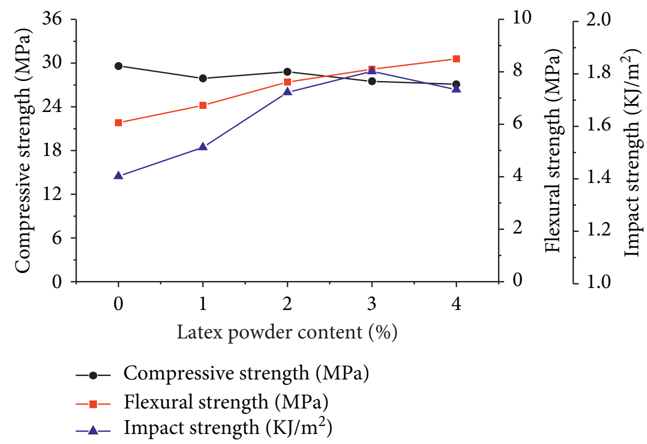

Figure 3: Dependence of latex powder content on mechanical properties of cement slurry.

toughness of cement paste and it quantitatively characterizes the toughening effect [25].

The compressive strength, flexural strength, and impact strength of the incorporated latex powder-cement pastes after one day of curing were tested using varied latex powder from 0 to 4 wt.%, and the results are shown in Figure 3. With increasing latex powder content, the flexural strength of samples increases, and the growth rate reduces. Increased up to 4 wt.%, the flexural strength is recorded as 8.5 MPa, which is about 40% higher in comparison with the free latex powder-cement slurry. Simultaneously, the impact strength rises with an optimum value recorded as 1.81 kJ/m^2 corresponding to 3 wt.% which reflects an enhancement of roughly 28% comparatively with the free latex powder-cement slurry. However, under identical condition, a reduction of compressive strength is noticed, but this could not significantly impede the cementing process. The latex powder is a kind of toughening material with better performance as it greatly improves the toughness of cement with a slight effect on the compressive strength.

3.2. *Effect of Rubber Content on the Properties of Cement Slurry*

3.2.1. Effect of Rubber Content on Conventional Properties. The dependence of rubber content ranging from 0 to 4 wt.% on the rheological properties, thickening time, and fluid loss of cement slurry was examined, and the results are presented in Table 3 and Figures 4 and 5. As observed in Table 3, the rheology of cement paste is strongly dependent on the content of rubber. With increasing the rubber content up to 3 wt.%, the Φ_{300} readings significantly increase to more than 300. Hence, the rubber content should not only be controlled, but addition of an appropriate amount of dispersant into the slurry is also necessary.

Represented in Figure 4 is the dependence of rubber content on the thickening time. It is noticed that, increased the rubber content up to 4 wt.%, reduces the thickening time

Table 3: Dependence of rubber content on rheological properties of cement slurry.

Sample number	Rubber content (wt.%)	Φ_{600}	Φ_{300}	Φ_{200}	Φ_{100}	Φ_6	Φ_3
P	0	283	187	132	73	7	3
R1	1	300+	281	202	113	14	7
R2	2	300+	291	203	116	13	7
R3	3	300+	300+	214	119	11	8
R4	4	300+	300+	238	139	18	13

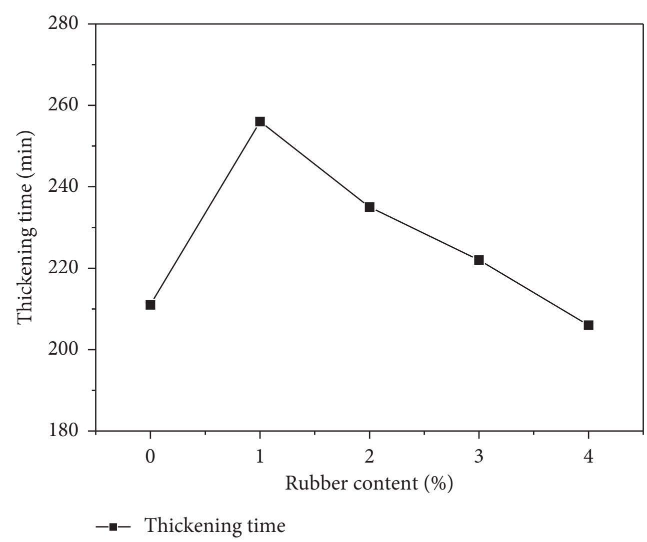

Figure 4: Dependence of rubber content on thickening time of cement slurry.

approximately by 5 min. However, this does not significantly affect the safety of the construction. The incorporated rubber-cement slurry demonstrates an appreciable retention of fluid. This is reflected by a roughly two-fold control (24 mL) at 4 wt.% in comparison with the free rubber-cement slurry (55 mL) as seen in Figure 5. This observation arose from the fact that the polymeric rubber reduced the motion of water into the cake pores by filling the pore spaces leading to prevent the cement slurry from losing water.

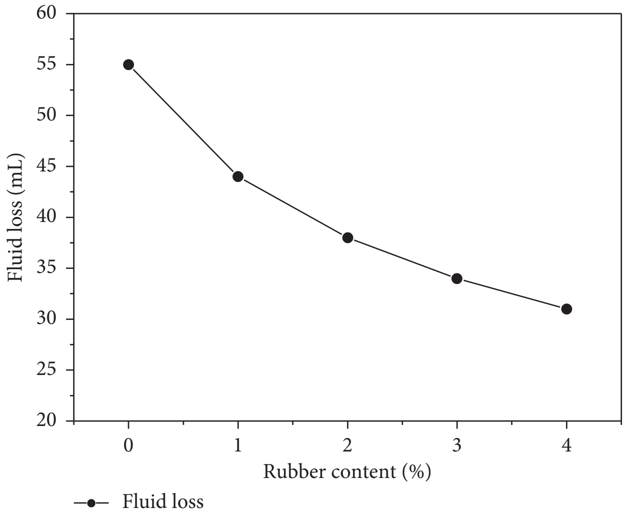

Figure 5: Dependence of rubber content on fluid loss of cement slurry.

3.2.2. Dependence of Rubber Content on Mechanical Properties. Rubber is a kind of elastic particle material. The dependence of rubber content ranging from 0 to 4 wt.% on the compressive strength, flexural strength, and impact strength of cement paste cured for one day was evaluated as indicated in Figure 6. With the increase of rubber content, the compressive strength continued to decrease while flexural strength increased and impact strength increased first and then decreased. Compared with rubber-free cement slurry, the compressive strength decreases by almost 35.1% while the flexural strength and impact strength both raises roughly by 41.9% and 26.2%, respectively, when the rubber is added within 4 wt.%. In the light of these results, the improvement of cement matrix modified with rubber as a flexible additive was evidenced.

3.3. Synergistic Effect of Latex Powder and Rubber on the Performances of Cement Slurry

3.3.1. Synergistic Effect of Latex Powder and Rubber on the Conventional Performances of Cement Slurry. Latex powder and rubber have an obvious effect on the conventional properties of cement slurry. The performance of incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR1 and LR2), incorporated 3 wt.% latex powder-cement slurry (L3), and incorporated 2 wt.% rubber-cement slurry (R2) were evaluated in comparison with the pure cement slurry (P), and the results are shown in Table 4 and Figures 7 and 8. It was noticed that the rheology values of the Φ_{300} reading of LR1 (the content of dispersant is 0.5 wt.%) was recorded to be more than 300 as indicated in Table 4. After adding an appropriate amount of dispersant, the rheological property of LR2 (the content of dispersant is 0.8 wt.%) meets field requirements. With reference to Figure 7, thickening time variation of LR2 is not remarkable. Hence, it cannot impede the safety of construction. Moreover, as seen in Figure 8, the synergistic effect of latex powder and rubber obviously reduces the fluid loss of cement slurry by about 36% in comparison with the pure cement slurry.

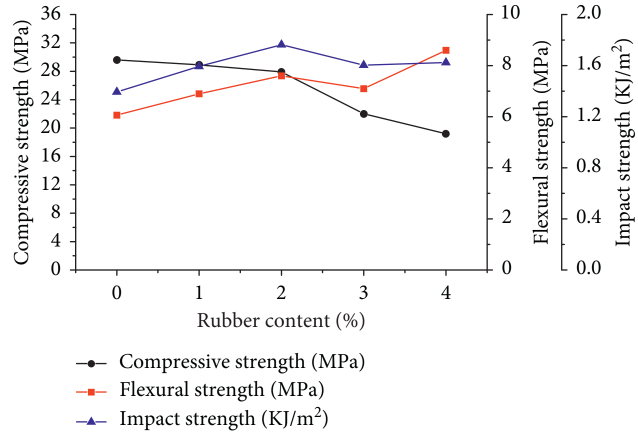

Figure 6: Dependence of rubber content on mechanical properties of cement slurry.

Table 4: Rheological properties of cement slurry with rubber and latex.

Sample number	Φ_{600}	Φ_{300}	Φ_{200}	Φ_{100}	Φ_{6}	Φ_{3}
LR1	300+	300+	239	167	29	21
LR2	300+	261	202	103	9	5

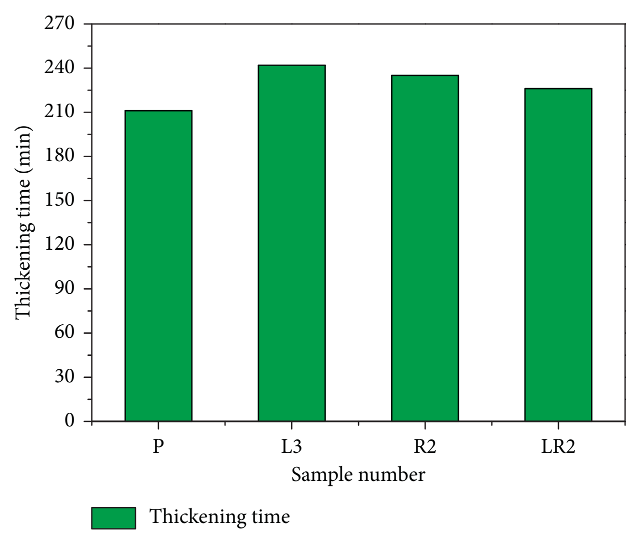

Figure 7: Dependence of rubber and latex on thickening time of cement slurry.

3.3.2. Synergistic Effect of Latex Powder and Rubber on the Mechanical Performances of Cement Slurry. In this section, the mechanical performance of incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) was evaluated in comparison with incorporated 3 wt.% latex powder-cement slurry (L3), incorporated 2 wt.% rubber-cement slurry (R2), and pure cement slurry (P), all kept in a standard curing molds at 90°C with 100% relative humidity for 1,

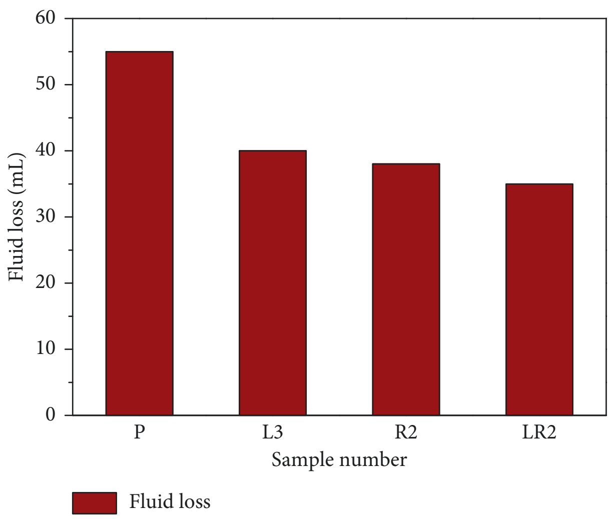

FIGURE 8: Dependence of rubber and latex on fluid loss of cement slurry.

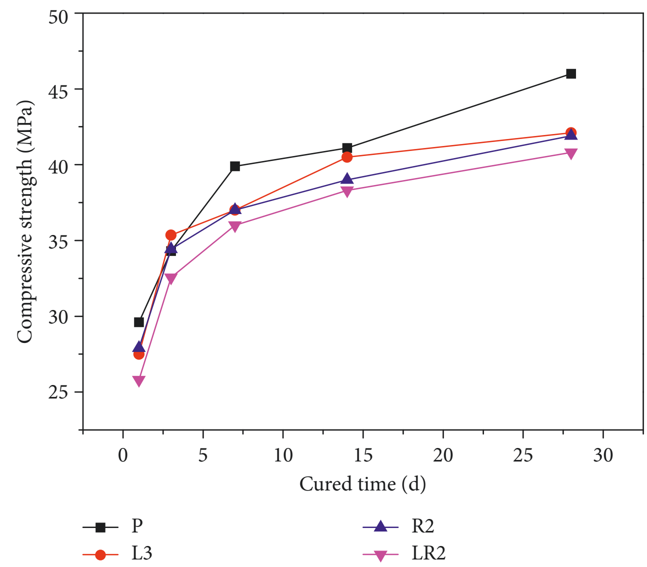

FIGURE 9: Compressive strength of cement slurry with curing time.

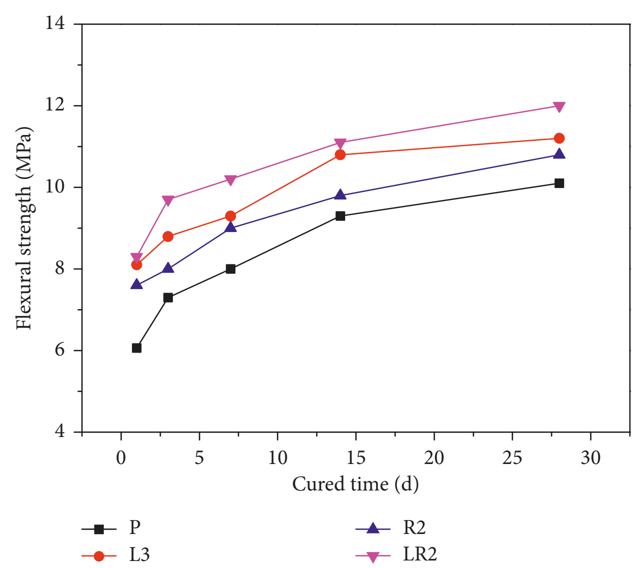

FIGURE 10: Flexural strength of cement slurry with curing time.

3, 7, 14, and 28 days. The compressive strength, flexural strength, and impact strength of the cement samples were tested under different curing times ranging from 1 to 28 days as represented in Figures 9–11.

When exposed to a prolonged curing time, the compressive strength, flexural strength, and impact strength of cement stone increase. However, 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) exhibits the lowest compressive strength in comparison with 3 wt.% latex powder-cement slurry (L3), 2 wt.% rubber-cement slurry (R2), and pure cement slurry (P) during the whole curing period as shown in Figure 9. Nevertheless, in comparison with 3 wt.% latex powder-cement slurry (L3), 2 wt.% rubber-cement slurry (R2), and pure cement slurry (P), the highest values of flexural strength and impact strength are observed in 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) as indicated in Figures 10 and 11. Under different curing times ranging from 1 to 28 days, the compressive strength of 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) experiences an increase of 58.1% (from 25.8 MPa to 40.8 MPa) which meets the requirements of field construction, and the flexural strength of 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) increase by about 44.6% (from 8.3 MPa to 12 MPa). After curing for 28 days, the compressive strength of 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) is 11.3% lower than that of pure cement (P), while its flexural strength is increased by 18.8%. Furthermore, with increasing curing time up to 28 days, the impact strength of 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) increases and even higher values are recorded comparatively with P (23.7%), L3 (4.4%), and R2 (6.8%). The combination of latex power and rubber enhances the ability of the cement sheath to resist downhole external load, although a slight influence is observed on the compressive strength.

3.3.3. Stress-Strain Behavior. The stress-strain of pure cement slurry (P), incorporated 3 wt.% latex powder-cement slurry (L3), incorporated 2 wt.% rubber-cement slurry (R2), and incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) within a curing time of 28 days were examined. The results are shown in Table 5 and Figure 12.

Flexible material reduces the elastic modulus of cement stone and increases the peak strain. The elastic modulus of 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) is the lowest in comparison with 3 wt.% latex powder-cement slurry (L3), 2 wt.% rubber-cement slurry (R2), and pure cement slurry (P). And it is about 47.9% lower than that of pure cement slurry, and the maximum strain increases by 96% as presented in Table 5. The stress-strain relationship reveals that the stress-strain curve of pure cement slurry is nearly straight, and it exhibits a brittle appearance when subjected to stress compression as a consequence of its quick collapse when it reaches

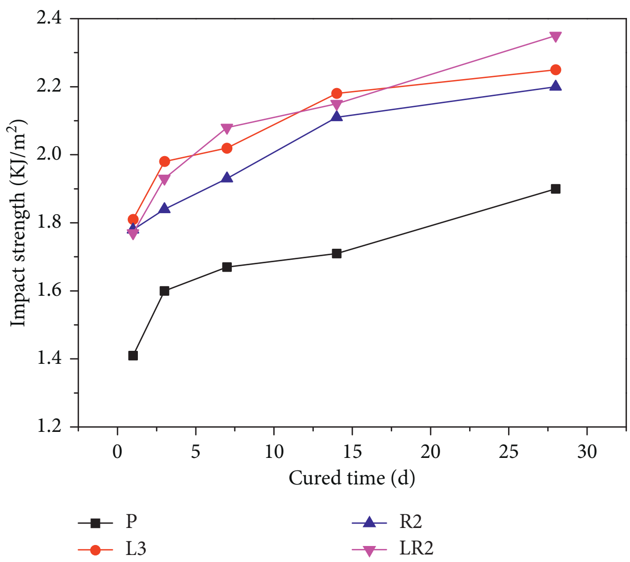

Figure 11: Impact strength of cement slurry with curing time.

a peak value. However, a straight line part is observed when the cement paste containing flexible material is subjected to compressive stress. With further loading, a nonlinear curve part appears with a continuous creep, reflecting the elastic deformation ability of the samples. Under identical stress conditions, 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) demonstrates the largest strain with a strong ability for deformation, as presented in Figure 12. From these analyses, it is once more evidenced that the hybrid material combination improved the ability of loading as well as tolerance of cement slurry. The synergistic action not only improved the elasticity of cement stone, but it also prevents and buffers any fractures of the cement sheath under downhole stress.

3.4. Micromorphology of Cement Stone with Latex Powder and Rubber. The micromorphology of incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2) was observed using SEM. Figures 13 and 14 display the synergism between latex powder and rubber. As shown in Figure 13, a clear micro-cross-linked structure and dispersed rubbers were formed in the cement matrix. The high magnification evidence in Figure 14 shows the three-dimensional network structure formed as a result of the synergetic effect in 3 wt.% latex powder + 2 wt.% rubber-cement slurry (LR2). Latex particles formed a continuous film which was adsorbed on the surface of the hydrated products, leading to a mutual penetration and formation of a three-dimensional network structure. During cement hydration, latex was involved in the formation of C-S-H gel network, as a result to form a unified structure with C-S-H gel phase which reduced the brittleness of cement stone [26]. Additionally, the modified rubber formed a flexible structure with rubber as a core in the cement paste [27]. Subsequently, the bonds created in between the cement matrix and rubber formed a plastic structure which increased the elasticity of the cement paste. Attributed to the synergistic effect between latex powder and rubber, the improved elastic matrix served as buffering effect on the external impact when the cement stone is subjected to the external stress condition. After fracturing, the network structure formed by latex powder and rubber bridged both sides of cement matrix fracture. In case of fracture expansion, more energy was consumed resulting in improved elasticity and toughness of the cement stone.

Table 5: The stress-strain test results.

Sample number	Peak stress (MPa)	Peak strain (%)	Elastic modulus (GPa)
P	46	0.5	9.4
L3	42.1	0.65	6.6
R2	41.9	0.8	5.9
LR2	40.8	0.98	4.9

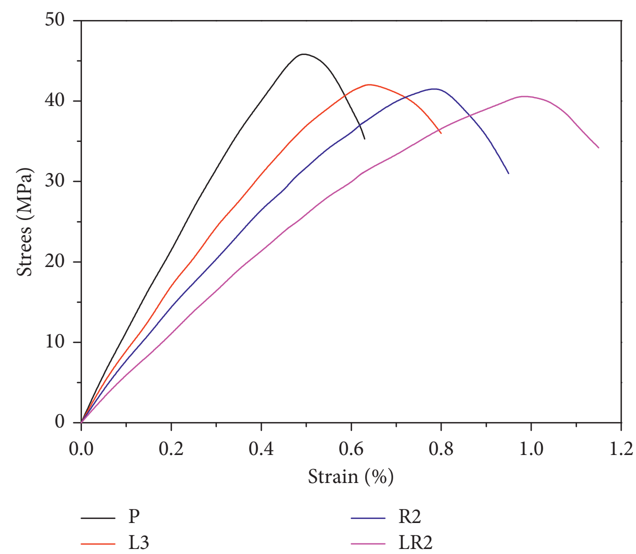

Figure 12: Curve of the stress-strain test.

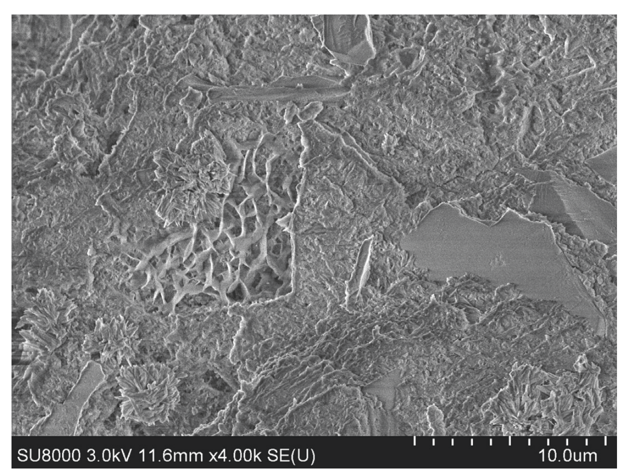

Figure 13: Micromorphology of cement stone LR2 (low magnification).

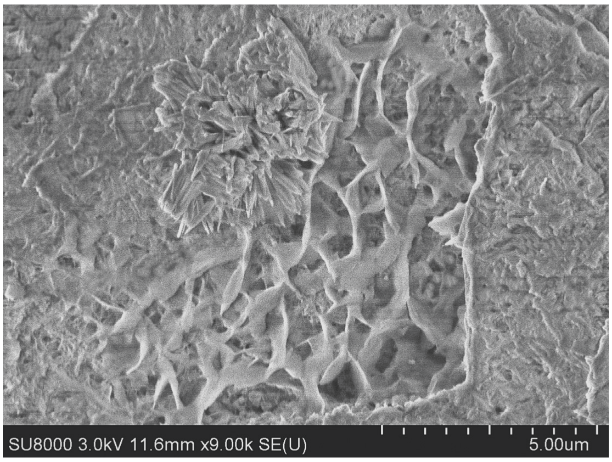

Figure 14: Micromorphology of cement stone LR2 (high magnification).

4. Conclusion

In this paper, the conventional and mechanical properties of cement samples including latex powder-cement slurry or rubber-cement slurry and their hybrid combination cement slurry were comparatively examined and the following conclusions were drawn:

(1) Despite the same dosage of dispersant (the content of dispersant is 0.5 wt.%), rheology values of incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry were the largest in comparison with incorporated 3 wt.% latex powder-cement slurry and incorporated 2 wt.% rubber-cement slurry. However, after adding an appropriate amount of dispersant (the content of dispersant is 0.8 wt.%), the rheological property of incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry meets the field requirements.

(2) The thickening time variations of incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry were negligible. Moreover, incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry demonstrated the lowest fluid loss followed by 2 wt.% rubber-cement slurry, 3 wt.% latex powder-cement slurry, and pure cement slurry.

(3) Exposition for a prolonged curing time led to increased compressive strength, flexural strength, and impact strength of all the cement samples. However, the compressive strength of the incorporated 3 wt.% latex powder + 2 wt.% rubber-cement slurry was lower, while its flexural strength and impact strength were higher than those of 3 wt.% latex powder-cement slurry and 2 wt.% rubber-cement slurry.

(4) The synergism between latex powder and rubber formed a three-dimensional network structure and a flexible structure with rubber as a core in cement stone which improved the elasticity and toughness of cement stone.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Jianjian Song designed and performed the experiments. Mingbiao Xu supervised the whole process. Weihong Liu and Xiaoliang Wang gave some advice about the article. Yumeng Wu had a hand in part of the experimental tests.

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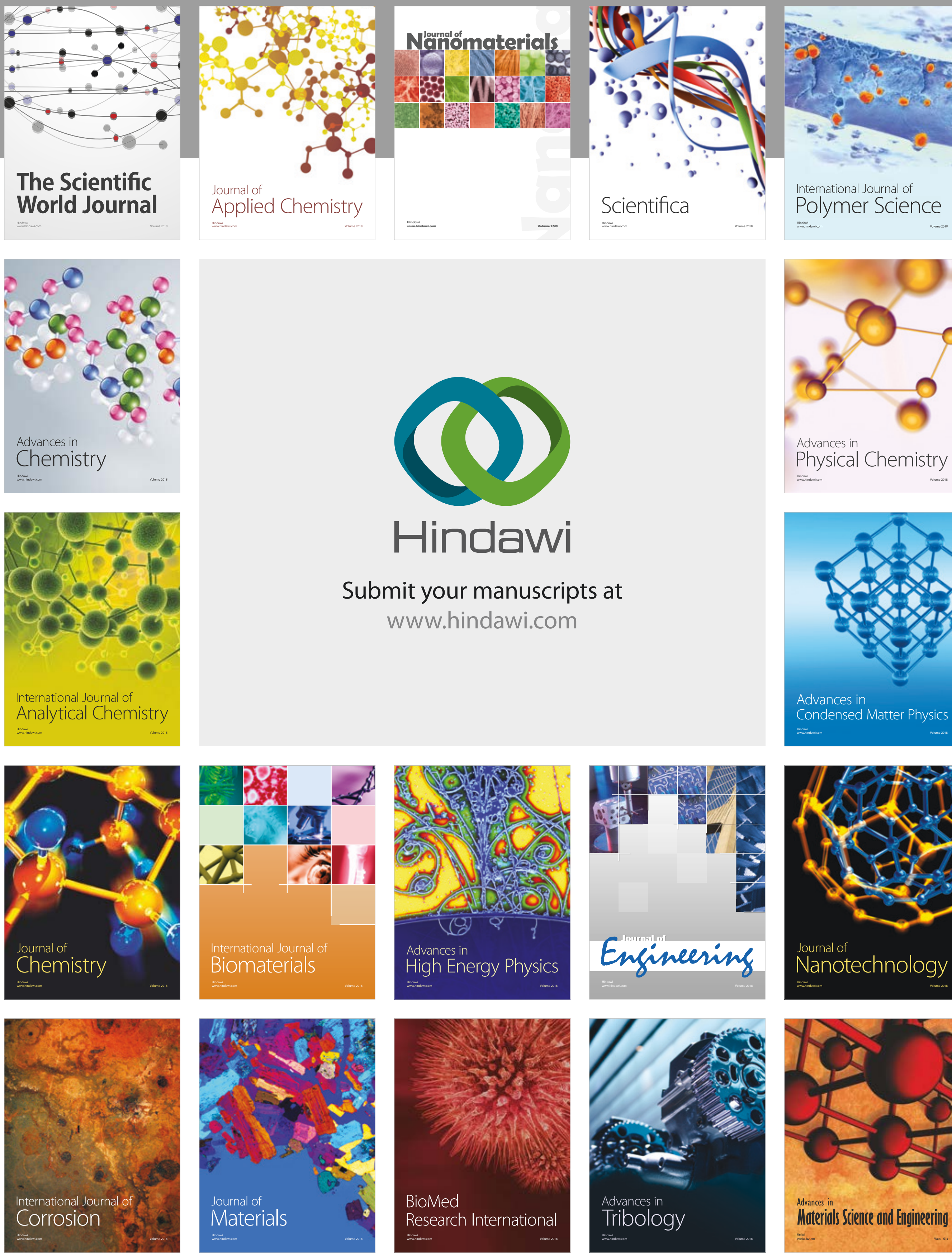
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