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Properties of concrete with a new type of saponin air-entraining agent

Quanbing Yang*, Peirong Zhu, Xueli Wu, Shiyuan Huang

College of Materials Science and Engineering, Tongji University, 100 Wu Dong Road, Shanghai, 200433, People's Republic of China

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Abstract

In the present paper, a new type of air-entraining agent (trademark SJ-2) is introduced, its main chemical component being triterpenoid saponin. Many properties of fresh and hardened concrete with SJ-2, such as workability, bleeding, air-bubble system, stability of air bubbles, strength loss, frost/salt-scaling resistance, etc., are measured. Some of them are compared with those of concrete with Vinsol resin and abietic soap (AS). Results show that SJ-2 is an air-entraining agent with high quality, and most of the properties of concrete with SJ-2 are not lower than those of concrete with Vinsol; at the same conditions, the flexural strength loss of concrete with SJ-2 is remarkably lower than its compressive strength loss.

Keywords: Saponin; Air-entraining agent; Concrete; Frost/salt-scaling resistance; Strength

A large number of chemical substances can be used as air-entraining agents of concrete. Many of these are refined by-products from various industrial processes, such as pulp, paper, and petroleum production. The most commonly used chemicals are sodium salts of wood resin (e.g. sodium-abietate, which is similar to Neutralized Vinsol resin, or just Vinsol resin, which has been widely used for a very long time), salts of fatty acids, salts of sulphonated hydrocarbon, alkyl-benzyl sulphonates, etc. [1].

One of the most commonly used air-entraining agents in the world is the so-called Vinsol resin, see above. However, two types of air-entraining agent, abietic soap (AS) or sodium abietate and sodium lignosulphonate are widely used in China. Both air-entraining agents have many shortcomings, such as bad air-bubble system, high air content loss, high strength loss per air content for sodium lignosulphonate; bad water-solubility, some precipitation formation when used with sulphonated naphthalene condensate or sulphonated melamine_formaldehyde condensate together and high strength loss for AS. These obvious shortcomings, especially high strength loss, badly influence the application of air-entraining agent, because the compressive strength is an important parameter for designing concrete in many Chinese standards.

A new type of air-entraining agent was first invented in 1988 and its quality has been improved significantly since then [2], its main component being a surface active substance, saponin. The admixture is refined from the fruits of some natural plants, such as Chinese honey locust. It has been widely used in many kinds of concrete since 1990, such as high frost-resistance concrete, pumping concrete, and so on. In total about 3 million m^3 of air-entrained concrete with SJ-2 has been produced.

1. Chemical composition and physical properties of SJ-2

1.1. Chemical composition

SJ-2 is a surfactant. The admixture is easily soluble in water and is stable in acid solutions or alkali solutions. It is also stable in hard water. The main component in SJ-2 is saponin. According to the results of IR analysis, the saponin is a triterpenoid compound, which is made up of aglycone and monosaccharide groups. Just because the saponin is a long organic molecule with a hydrophilic end and a hydrophobic end, it can easily concentrate at the interface, and therefore it can reduce the surface tension and smaller air-entraining bubbles can be formed.

* Corresponding author. Tel.: +86-21-6590-1021; fax: +86-21-6590-1009.

E-mail address: qbyang@public9.sta.net.cn (Q. Yang).

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Table 1
Physical properties of SJ-2 (powder product)

Color	Density	Water content	Insoluble substance	Volatile component
Primrose yellow	1.3 g/cm^3	< 5%	Negligible	Negligible

1.2. Physical properties

There are two states of SJ-2, i.e., dry powder and liquid products. In the present test the powder was used. The properties of the powder product are shown in Table 1.

The generated air-bubble volume or the foam capacity, and the foam (bubble) stability of a water solution of SJ-2 were measured according to Chinese standard JGJ 56-84. The test results are shown in Table 2. The stability is defined as the foam volume after 5 min divided by the initial volume. No comparison of the foam capacity and stability with Vinsol resin was made.

The solid product of SJ-2 is very soluble and no precipitation occurs when it is used with superplasticizers (SPs) of type sulphonated naphthalene condensate or sulphonated melamine-formaldehyde condensate together. Therefore, SJ-2 is commonly mixed with these SPs to produce compound admixtures in China, such as pumping admixture.

2. Experimental

2.1. Raw materials

525# ordinary Portland cement with specific area of 330 m^2/kg, river quartz sand with the fineness modulus of 2.57 and crushed aggregate with the size of 5–25 mm were used. In order to evaluate some properties of concrete with SJ-2 air-entraining agent, two other air-entraining agents, Vinsol resin from United States and AS were used for controlling admixtures. A sulphonated naphthalene-formaldehyde SP is also used, which is a liquid product with about 32% dry powder.

2.2. Concrete proportions s and specimens

The proportion of reference concrete is cement/water/aggregate/sand = 1:0.55:3.37:2.24, its slump is about 6 cm and the cement content is about 330 kg/m^3. Air-entrained concrete is prepared by adding air-entraining agents into the reference concrete. The air content of the reference concrete is assumed as 1%.

Table 2
Properties of SJ-2 solutions according to Chinese standard JGJ 56-84

Concentration (%)	Air-bubble volume: Initially	Air-bubble volume: After 5 min	Stability (%)	pH value
0.40	52	47	90.4	6.89
0.65	61	55	90.2	6.37
0.80	67	61	91.0	6.01

Specimens with sizes of 10 × 10 × 10 cm and 10 × 10 × 40 cm were cast, with the former specimen being used for compressive strength and salt-scaling tests, and the latter for flexural strength and frost tests. The specimens were demoulded after 1 day and were then stored in water at 20 ± 2°C.

2.3. Frost/salt scaling tests

Salt-frost scaling test is similar to the CDF test method recommended by the RILEM Technical Committee TC-117 [3]. However, one freeze–thaw cycle is frozen at − 20 ± 2°C for 3 h and then thawed at 20 ± 5°C for 3 h. The deicer solution is 4% NaCl. After curing in water for 28 days, the single surface of the cube specimen is submerged into 4% NaCl solution in a depth of about 4 mm in a plastic container that is covered by a tight lid during the test. The salt solution is changed about every seven cycles.

The frost test is according to the Chinese standard method GB8076-97 (rapid test).

3. Results and discussion

3.1. Properties of fresh concrete

3.1.1. Slump and bleeding

The workability of fresh concrete is significantly improved due to the generation of a lot of micro-air bubbles when an air-entraining agent with high quality is added, i.e., its slump is enhanced, but its bleeding and segregating capacity is reduced and therefore the cohesiveness and homogeneity of concrete are enhanced. These effects are especially obvious for dry-mix concrete, concrete with low cement paste, and so on.

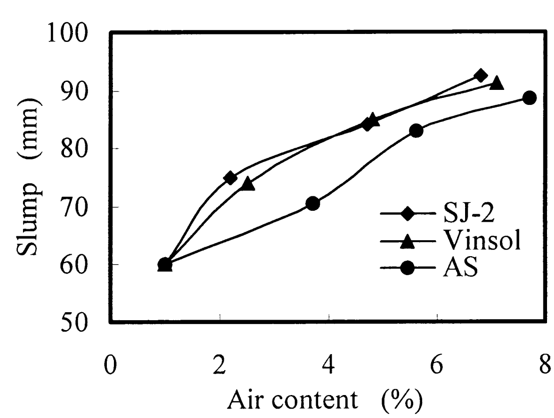

Fig. 1. Effects of air-entraining agent on the slump of fresh concrete.

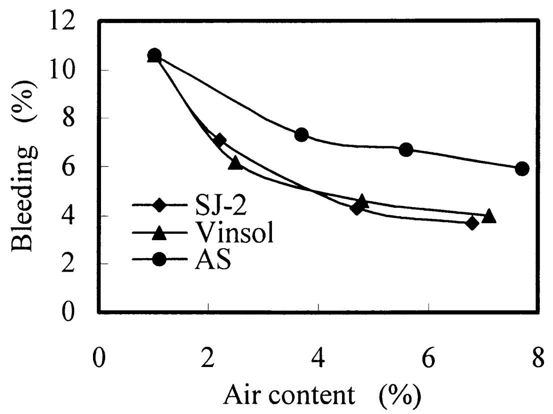

Fig. 2. Effects of air-entraining agent on the bleeding of fresh concrete.

Effects of air content and type of air-entraining agent on slump and bleeding of fresh concrete are shown in Figs. 1 and 2. From Fig. 1 it can be seen that the slump of fresh concrete increases with the air content, but the increased rate is reduced when the air content is over some value. Fig. 2 shows that the bleeding of fresh concrete is reduce with the increase in the air content. The effects of SJ-2 on the slump and bleeding are similar to those of Vinsol, but the slump-increase and bleeding-reduction effects caused by AS are lower than those of SJ-2 or Vinsol.

The SJ-2 air-entraining agent has been widely used since 1990 in pumping concrete and ready-mixed concrete just because of these effective actions.

3.1.2. Air content

Results on relationships between air content, amount of SJ-2 and slump are given in Fig. 3. The method for measuring the air content of fresh concrete is according to ASTM C 231. It is indicated that the air content of fresh concrete increases with the amount of SJ-2 in a linear fashion. However, the air content is reduced at the same amount of SJ-2 when SJ-2 is used with a sulphonated naphthalene-formaldehyde SP together. Moreover, the air content decreases with the increase in the slump. These phenomena also occur for other air-entraining agents [4–6].

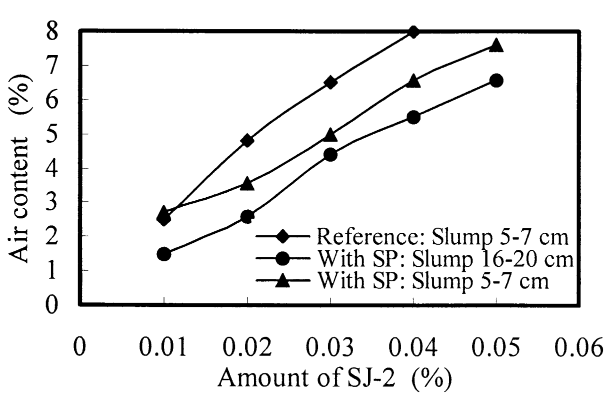

Fig. 3. Relationships between air content, amount of SJ-2 and slump.

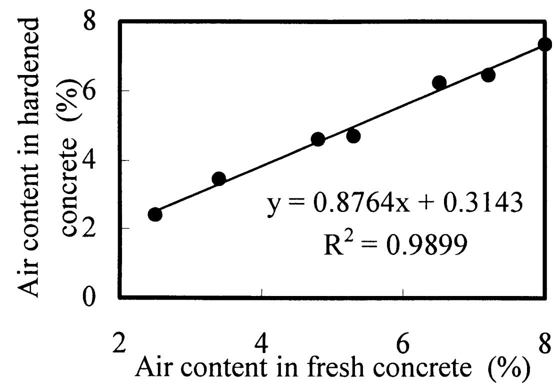

Fig. 4. Relationship between air content in fresh concrete and that in hardened.

3.2. Properties of hardened concrete

3.2.1. Air content and air-bubble parameters

Fig. 4 gives the result on the relationship between air content in fresh concrete and that in hardened concrete. It is shown that, at the same cement content and W/C, the air content in hardened concrete (Y) increases with that in fresh concrete (X) in a linear fashion:

$$Y = 0.8764X + 0.3143(\text{samplenumber}n = 7, R = 0.995).$$

From this equation it can be clearly seen that the air content in hardened concrete have a bigger loss compared with that in fresh concrete when the air content is higher, but the air bubbles entrained by SJ-2 is considerably stable, which is consistent with the result in Table 2.

The main reason to high stability of air bubbles entrained by SJ-2 is that these bubbles are very small, i.e., the specific area of these bubbles is high. Results on the air-bubble parameters are shown in Fig. 5, with the analyzing method according to ASTM C 457. It is shown that the specific area of air bubbles entrained by SJ-2 is quite high, over 31.2 mm^{-1} for the air content of 2.5–8%, but the specific area have a reduced tendency with the increase in the air content

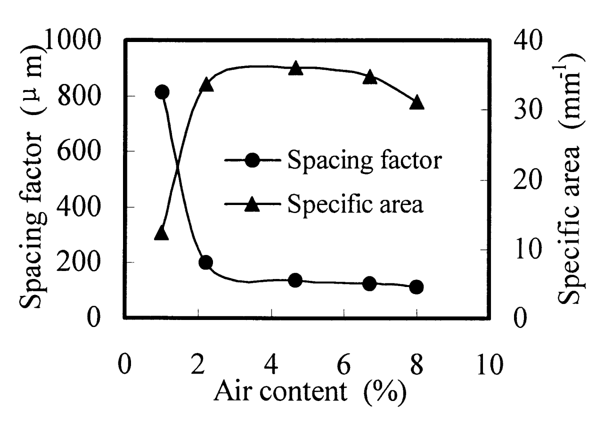

Fig. 5. Relationships between air content, spacing factor and specific area in hardened concrete.

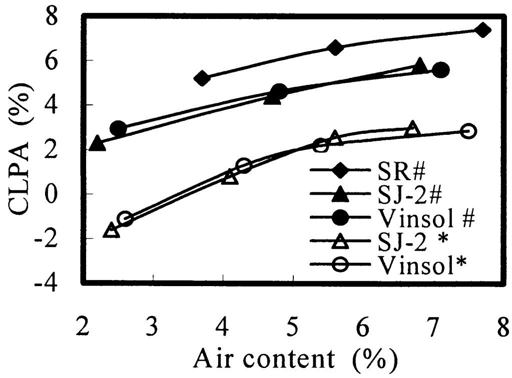

Fig. 6. Effects of air content on CLPA. #, same W/C; *, same slump.

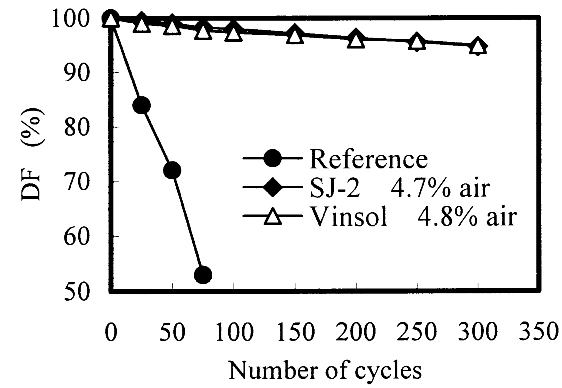

Fig. 8. The frost resistance of concrete with SJ-2 and Vinsol.

when the air content is over some value. It is due to this that small bubbles have a natural tendency to coalesce to form larger bubbles.

Fig. 5 also clearly shows that the spacing factor of concrete is obviously reduced after SJ-2 is added into it, but this tendency becomes slower when the air content is over about 4%. Consequently, the frost/salt-scaling resistance of concrete with SJ-2 is of course improved remarkably.

3.2.2. Compressive strength

One main shortcoming of air-entraining agents is that the compressive strength of concrete decreases with the increase in the air content. Generally, the compressive strength loss per air content (CLPA) is about 4–6%. Results on effects of air content on the 28-day CLPA are displayed in Fig. 6. It indicates that at the same cement content and W/C, CLPA increases with the air content of concrete. The effect of SJ-2 on CLPA is almost the same as that of Vinsol, but CLPA caused by AS is obviously higher than that by SJ-2, which may be because the air-bubble system of AS is worse than that for SJ-2 or Vinsol. CLPA caused by SJ-2 is about 2–5% for the air content of 2–6%.

However, the workability of concrete is improved with the increase in the air content, and therefore the water content can be reduced, i.e., the W/C ratio of concrete with air-entraining agents is lower. CLPA of the air-entrained concrete can of course be reduced at the same cement content and slump. Results in Fig. 6 prove this conclusion. The compressive strength of concrete with SJ-2 is not reduced, but have some increase when the air content is below about 3.5%. Even though the air content of concrete is about 3.5–7%, CLPA caused by SJ-2 is still lower than 3%.

3.2.3. Flexural strength

The flexural strength is a very important parameter for designing pavement concrete in China. From results on the flexural strength of air-entrained concrete in Fig. 7, it is surprisingly found that for the same cement content and slump the flexural strength of concrete with the air content of 2–7% is obviously higher than that of concrete without SJ-2. Even for the same W/C ratio, the flexural strength of concrete with SJ-2 is still somewhat higher than that of concrete without SJ-2 when the air content is below about 4.5%. For the air-entrained concrete, the flexural strength is reduced with the increase in the air content, but this reduction is very low compared with that of the compressive strength of the concrete. These results infer that the toughness of concrete with SJ-2 increases with the air content, the result in Fig. 7 that the compressive/flexural

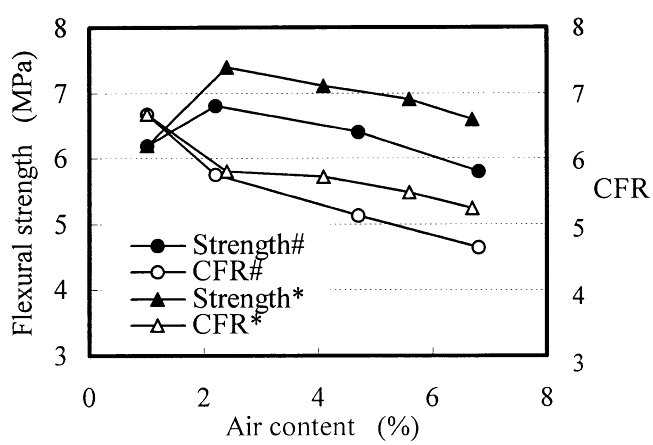

Fig. 7. Effect of air content on the flexural strength and CTR of concrete. CTR, compressive/flexural strength ratio; #, same W/C.

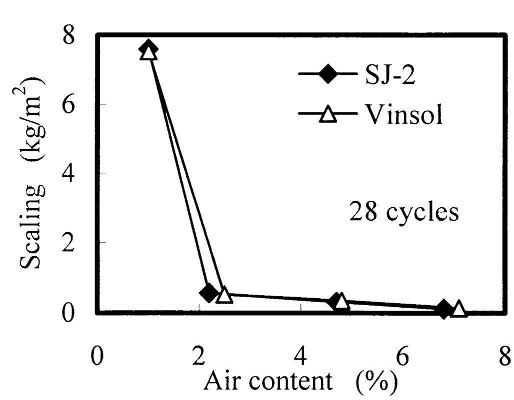

Fig. 9. Salt-scaling resistance of concrete with SJ-2 and Vinsol.

strength ratio (CFR) is enhanced with the air content indirectly proves this conclusion.

The above results are very useful for pavement concrete. Now, they are widely applied to pavements in China.

3.2.4. Frost/salt-scaling resistance

The results of the frost/salt-frost test are shown in Figs. 8 and 9. From Fig. 8 it is clearly shown that the frost resistance of concrete with SJ-2 and Vinsol (about 4.7% air content) is much higher than that of the reference concrete. For example, for the reference concrete, its DF value is only about 52% after 75 cycles, but that of concrete with SJ-2 or Vinsol is still high, about 94% even after 300 cycles.

Fig. 9 indicates that the salt-scaling resistance of concrete is substantially improved after being air-entrained by SJ-2 and Vinsol. The main reason is that the air spacing factor of concrete is remarkably reduced after being air-entrained (see Fig. 5).

These results prove that the effective action of SJ-2 on the frost/salt-scaling resistance of concrete is almost the same as that of Vinsol.

4. Conclusions

SJ-2 is a new air-entraining agent with high quality, with its main chemical component being triterpenoid saponin. Concrete with SJ-2 possesses many good properties, such as high stability of air bubbles, good air-bubble system and workability, low bleeding and compressive strength loss, high frost/salt-scaling resistance, etc. Many properties of concrete with SJ-2, such as workability, air-bubble system, CLPA, frost/salt-scaling resistance and so on, are not lower than those of concrete with Vinsol.

It is surprisingly found that for the same cement content and slump the flexural strength of concrete with the air content of 2–7% is obviously higher than that of concrete without SJ-2. Even for the same W/C ratio, the flexural strength of concrete with SJ-2 is still somewhat higher than that of concrete without SJ-2 when the air content is below about 4.5%. It means that the compressive/flexural strength ratio of concrete with SJ-2 increases with the air content, which indirectly infers the increase in the toughness of the air-entrained concrete.

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