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BASIC PROPERTIES OF WELAN GUM AS A VISCOSITY AGENT AND ITS EFFECTS ON THE SELF-CONSOLIDATION OF FRESH CONCRETE

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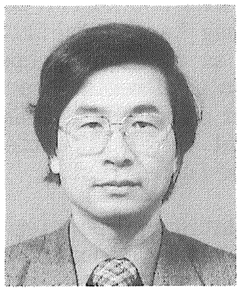

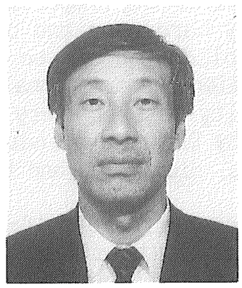

Noboru SAKATA Kyuichi MARUYAMA Masayoshi MINAMI

It has been reported that a suitable quantity of the viscosity agent Welan gum, which is a kind of natural water-soluble polysaccharide, effectively stabilizes the rheological properties of highly fluidized concrete. In this paper, we study the basic properties of Welan gum experimentally as well as the effects of Welan gum on fresh concrete, especially its self-consolidating properties. We find that the viscosity of an aqueous solution of Welan gum is not affected by calcium concentration nor pH, aside from a slightly high viscosity in an alkaline solution. We also learn that it stabilizes the rheological properties and mobility in confined spaces of highly fluidized concrete when a suitable quantity is added to the concrete. Further, it offers long-term stability and improves the self-consolidating properties over a wide range of slump-flow. We partially clarify how these effects arise.

Keywords: highly fluidized concrete, viscosity agents, rheological properties

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Noboru Sakata is a manager at the Hokuriku branch of Kajima Corporation. He obtained his D.Eng. from Nagaoka University of Technology in 1997. His research interests include dam concrete, thermal cracking stress, and highly fluidized concrete. He is a member of the JSCE.

Kyuichi Maruyama is a Professor in the Department of Civil Engineering at Nagaoka University of Technology, Niigata, Japan. He obtained his D.Eng. from Texas University in 1976. His research interests include cracking, concrete shear and fatigue, partially prestressed concrete, and high-performance concrete. He is a member of the JSCE.

Masayoshi Minami is a manager at the research center of Sansho Co.,Ltd. His research interest is polymer chemistry for civil engineering. He is a member of the JSCE.

1.INTRODUCTION

Self-consolidating concrete [1], [2] has been studied and developed by many laboratories since it was first advocated by Professor Okamura of Japan's Tokyo University. This type of concrete is now being applied not only to general structures, but also to very-large-scale constructions and very important structures. Self-consolidating concrete is defined as a concrete with self-consolidating properties that does not suffer defects such as shrinkage during early hardening and offers long-term durability. In this definition, self-consolidation can be defined as a set of properties that not only includes excellent deformational but also good resistance to material separation, and the ability to fill every nook and corner of a frame without vibration. A report [3] by Dr.K.Ozawa indicates that these properties can be estimated through two tests, slump flow and the V-type funnel test.

In general, the self-consolidating properties of highly fluidized concrete depend on the mix proportion, material qualities, and variations in quality. This means that there is some difficulty in producing a highly fluidized concrete with stable fluidity and good consolidating properties. To stabilize fluidity, which greatly affects self-consolidation, the use of a viscosity agent has been investigated. It has been reported on the basis of indoor tests [4] in the laboratory and actual field tests [5] that Welan gum, a kind of natural polysaccharide, is extremely effective at stabilizing the fluidity of concrete.

In the above two reports, it was shown that the addition of Welan gum minimizes fluidity variations as measured by mortar flow tests and slump flow tests. However, the effects of adding Welan gum on the consolidating properties of highly fluidized concrete were nor evaluated in detail.

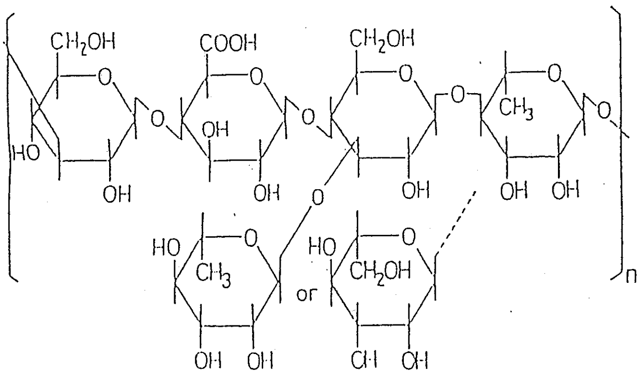
In this report, typical properties of Welan gum as a viscosity agent for highly fluidized concrete are evaluated experimentally. Also described are the detailed effects of Welan gum on fluidity, flowability in confined spaces, resistance to separation, and self-consolidation.

2.TYPICAL PROPERTIES OF THE VISCOSITY AGENT WELAN GUM

2.1 Chemical structure

Welan gum is a kind of natural polysaccharide and its chemical structure is shown in Figure 1 [6]. The backbone is a repeating unit of four saccharides and it comprises D-glucose, D-glucuronic acid, D-glucose, and L-rhamnose units. The side chain is either an L-mannose or L-rhamnose unit. In water solution, Welan gum is thought to have a double-helix structure or super-associative structure like the typical fermentative polysaccharide, xanthan gum, which is shown in Figure 2 [7]. Methyl cellulose, a viscosity agent typically used in underwater concrete, is not thought to have such a super-associative structure, since there is a linear relationship between the logarithm of its viscosity and the logarithm of its average molecular weight [8].

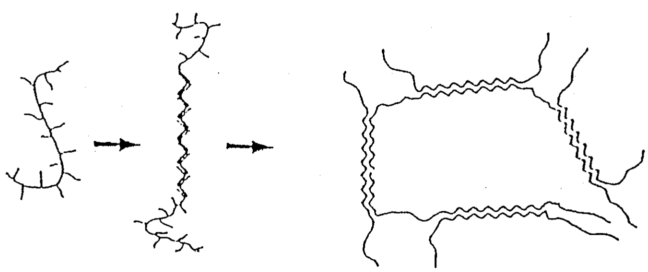
The estimated molecular weight of Welan gum is reported to be 2×10^6, but it has not been verified as yet. Depending on the method of measurement, a wide range of results is obtained as a result of its double-helix or super-associative structure in solution. Even in reports on xanthan gum, which has a similar structure and has been studied many times since 1964, molecular weight has been reported as $15\times10^6 \sim 5\times10^6$ [6], [9], $3\times10^6 \sim 7.5\times10^6$ [6], [7], and 3×10^5 [5], [10].



→3)-β-D-Glcp-(1→4)-β-D-GlcpA-(1→4)-β-D-Glcp-(1→4)-α-L-Rhap-(1→
3
↑
1
α-L-Rhap or α-L-Manp

D-Glcp : D-glucose
D-GlcpA : D-glucuronic acid
L-Rhap : L-rhamnose
L-Manp : L-mannose

Fig.1. Chemical structure of Welan gum



Rondon structure | Double helix structure | Super-associative structure

Fig.2. Schematic illustration of xanthan gum solutions

【Carbon resource 】 ⇨ 【Aerobic fermentation】 ⇨ 【Dilution】 ⇨ 【Sterillization】 ⇨ 【Filtering 】 ⇨ 【Precipitation 】 ⇨ 【Filtering 】 ⇨ 【Drying】 ⇨ 【Milling 】 ⇨ 【Product 】

(bacterium) Welan gum:*Alcaligenes* ATTC31555

Fig. 3. Production process of Welan gum

2.2 Production method

Welan gum is produced by aerobic fermentation using the Alcaligenes strain ATCC31555. The process is shown in Figure 3; it is almost identical to that of other fermetative polysaccharides such as xanthan gum [11]. In the commercial production of Welan gum, a single-species fermentation is carried out using freeze-dried bacterial stock or some of the broth from a relatively young fermentation. Final fermentation takes place after a few fermentation scaling-up steps under conditions of aeration and agitation. The source of carbon is glucose, sugar, starch, or hydro-decomposed starch. The concentration of glucose is maintained at 1% to 5% and the temperature is maintained at 28 ℃ during the continuous fermentation. The pH is kept approximately neutral by the addition of phosphate buffer. Ammonium nitrate or soybean peptone are used as a nitrogen source, and small quantities of metal salts (such as iron, magnesium, molybdenum, cobalt, zinc, copper, manganese, and boron, etc.) are also added [11]. The final broth is diluted and sterilized in a thermal exchanger. After sterilization, bacteria and impurities are removed by filtration or centrifuge, and the fermented gum is precipitated and recovered by the addition of iso-propyl alcohol. This is Welan gum, and it is dried and milled for marketing as a product.

2.3 Rheological properties

There are many natural polysaccharide-based viscosity agents aside from Welan gum, including xanthan gum, guar gum, Curdlan and others. Hundreds of thousands or even millions of such polysaccharides are known.

In this section, the rheological properties of concrete made with Welan gum are examined in order to investigate the mechanism by which Welan gum affects concrete. Comparisons are discussed with xanthan gum and guar gum as typical natural polysaccharide-based viscosity agents, Methyl Cellulose (MC) and Hydroxy Ethyl Cellulose (HEC) as typical cellulose-based viscosity agents used in underwater concrete, and polyacrylate. The chemical structures of these viscosity agents are shown in Figure 4.

2.3.1 Effect of water

The object of this study is to clarify the effects of the viscosity agents on viscosity with various forms of water. Solutions of the various viscosity agents were made up using deionized water, alkaline solution (2% sodium hydroxide and a saturated concentration of calcium hydroxide), filtered cement water dispersion A (100g of cement in 1,000g of deionized water) and filtered cement water dispersion B (300g of cement in 1,000g of deionized water). Viscosity was measured at 60 rpm in a BM viscometer manufactured by Tokimeck Co. Measurements were carried out three times an each sample by reading the indicator 30 seconds after starting rotation. Viscosity values were calculated as the average of the three data. Concentrations of each viscosity agent were chosen in the range 1% to 2% so as to give almost the same viscosity as a 1% Welan gum solution in deionized water. In past applications, the standard level of Welan gum in highly fluidized concrete was 0.05% of the water content. However, the Welan gum concentration in the free water is estimated to be 1%, hence the choice of a 1% concentration as the standard in these tests. Free water is assumed to be the water squeezed out of the paste after 10 minutes of centrifuging at 3,000 rpm. The paste contains 0% to 2% of super-plasticizer (β-naphthalene sulfonate) to cement content in a system with a 30% water/cement ratio. As shown in Figure

5, the proportion of free water to total water content is approximately 5% in the case of the higher concentration of super-plasticizer.

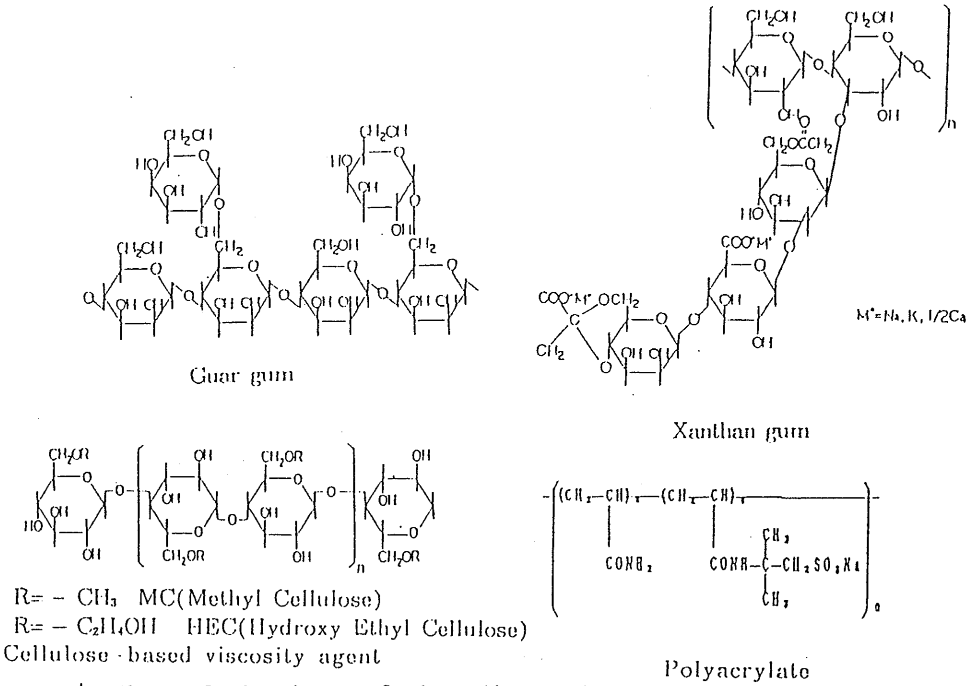


Fig.4. Chemical structures of viscosity agents

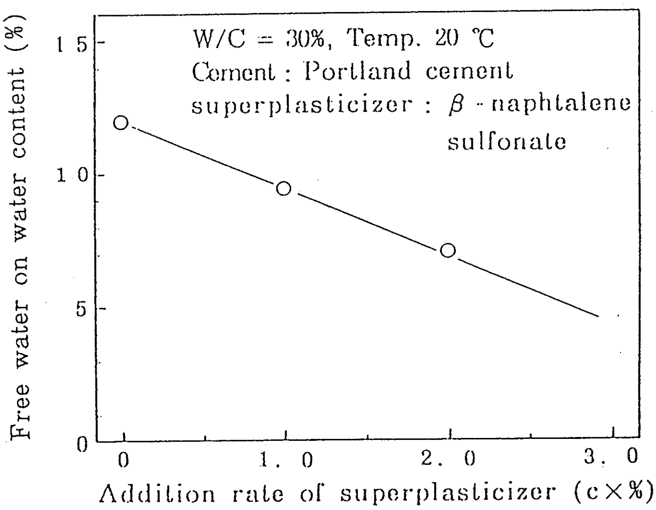


Fig.5. Relationship between free water on water content and SP addition

Figure 6 shows the viscosity of the solution containing each viscosity agent with the various forms of water. Welan gum provides almost the same viscosity with all water forms, except that it tends to be a little higher in the alkaline solution and filtered cement water dispersions than in deionized water.

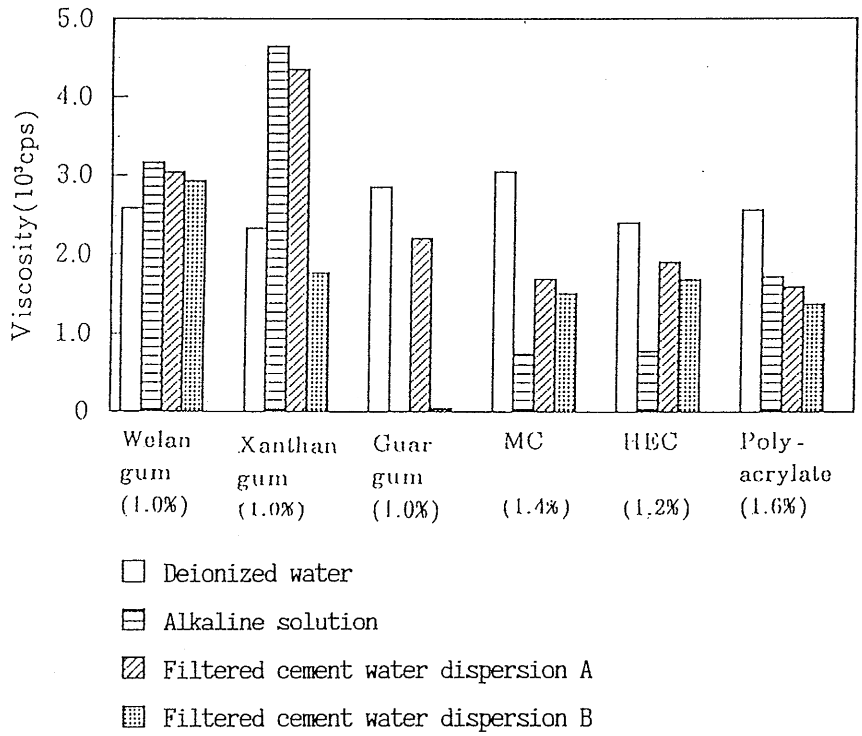


Fig.6. The viscosities of the solution containing esch viscosity agent with the various forms of water

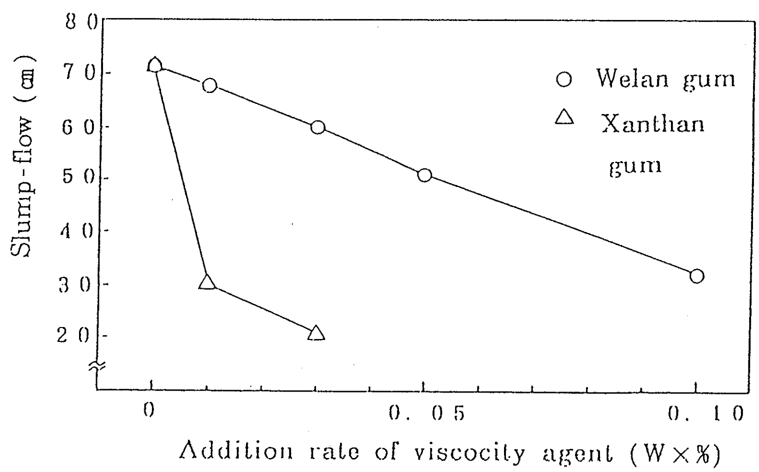


Fig.7. Relationships between slump flow and addition rate of viscosity agent

Xanthan gum gives a higher viscosity than Welan gum with the alkaline solution, but with the filtered cement water dispersions, the viscosity provided by xanthan gum solution is lower when the cement concentration is higher. It is assumed that xanthan gum interacts strongly with the calcium in the cement, leading to gelation and the development of higher viscosity under lower cement concentrations [7]. It is also thought that viscosity falls because of aggregation of the xanthan gum and precipitation with calcium under higher cement concentrations.

Figure 7 shows the relationship between slump flow and gum concentration when Welan gum or xanthan gum is added to highly fluidized concrete. The materials and mix proportion used in this test are shown in Tables 1 and 2. The slump flow of highly fluidized concrete was significantly lower with xanthan gum, even when the xanthan gum concentration was extremely low-- perhaps because the xanthan gum aggregated in the concrete. Guar gum is insoluble in a strong alkaline system, so it provided hardly any added viscosity with the alkaline solution and or higher water-cement concentrations.

In the case of cellulose-based derivatives (MC & HEC) and polyacrylate viscosity agents, the viscosity of solutions made with the alkaline solution and filtered cement water dispersions was lower than those using deionized water. There were large changes in viscosity with some kinds of water. These results indicate that the viscosity agents are affected by differences in cement concentration resulting from changes in water-cement ratio, and it would appear that these agents can be used to vary the flow properties and/or the consolidating properties of concrete. Welan gum is able to provide slightly greater viscosity with an alkaline solution than with deionized water.

To investigate these findings in more detail, the effects on viscosity of pH and calcium concentration in the presence of Welan gum and MC solution were measured at 25 ℃ and 60 rpm in a BM viscometer (Tokimeck Co.). Measurements were carried out three times for each sample by reading the indicator 30 seconds after starting rotation. Viscosity values were calculated as the average of these three data. Figure 8 shows the viscosity in the case of the two kinds of viscosity agent in solutions containing 1%, 5%, or 10% of calcium chloride with neutral pH. The solutions of viscosity agents were agitated for one hour before measurement. As the graph shows, the viscosity of solutions containing both Welan gum and MC increased as the calcium chloride concentration increased. Figure 9 shows viscosity versus pH (2 to 12), using hydrogen chloride and sodium hydroxide in deionized water. The viscosity of solutions containing Welan gum did not vary substantially over a wide pH range. On the other hand, the viscosity of solutions containing MC fell as the solution became more acid or alkaline. It can be concluded from these tests that the viscosity of filtered cement water dispersions containing Welan gum increases a little with rising calcium concentration and that the viscosity of filtered cement water dispersions containing MC decrease as the pH rises, or the solution becomes more alkaline.

2.3.2 Effects of temperature

To understand the effects of temperature on the viscosity provided by viscosity agents, the viscosity developed by 1% solutions of each viscosity agent was measured at 5, 10, 20, and 30 ℃ at 60 rpm in a BM viscometer. Measurements were carried out three times in each case by reading the indicator 30 seconds after starting rotation. Each viscosity value was calculated as the average of the three data. An alkaline solution was used as the solution. In this test, guar gum was not examined because it is insoluble in an alkaline solution. Figure 10

Table 1. Property of materials

Notation	Name	Specific gravity	Blaine value(cm^2/g)etc.
C	Ordinary Portland cement	3.16	Blaine 3790
SD	Limestone dust	2.70	Blaine 3210
S	Sand	2.57	River sand, Absorption 1.53(%) F.M. 2.62
G	Gravel	2.65	Crushed stone, Max.agg.size 20(mm) Solid Volume 60(%) F.M. 6.65
SP	β-naphtalene sulfonate	—	—
VA	Welan gum or Xanthan gum	—	—

Table 2. Mix proportion

Water cement ratio (%)	Water powder ratio (%)	G/Glim (%)	Unit weight(Kg/m^3)					SP * (%)	VA ** (%)
			W	C	SD	S	G	(P × %)	(W × %)
52.9	32.0	55	175	331	216	691	878	1.5	0-0.10

* Caluculated on the basis of (C+SD) weight
** Caluculated on the basis of water weight

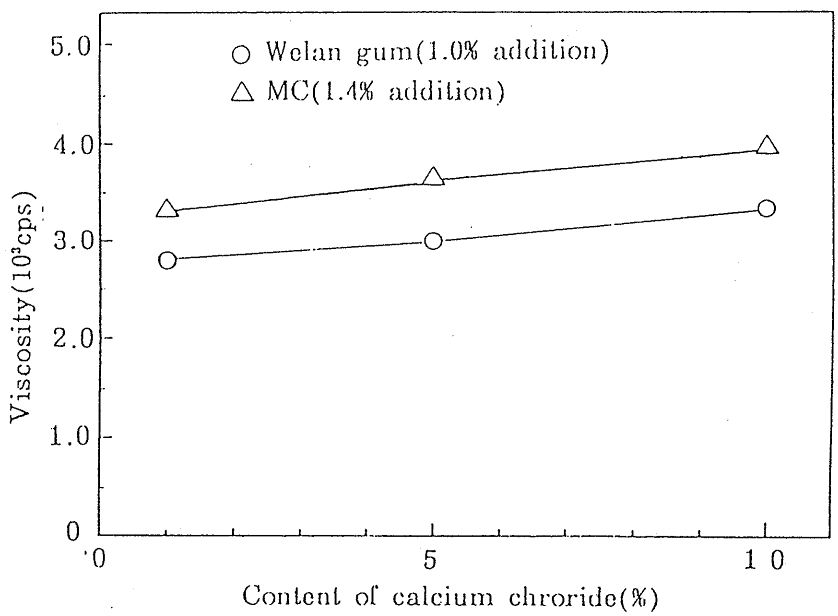


Fig.8. Relationships between viscosity and content of calcium chroride

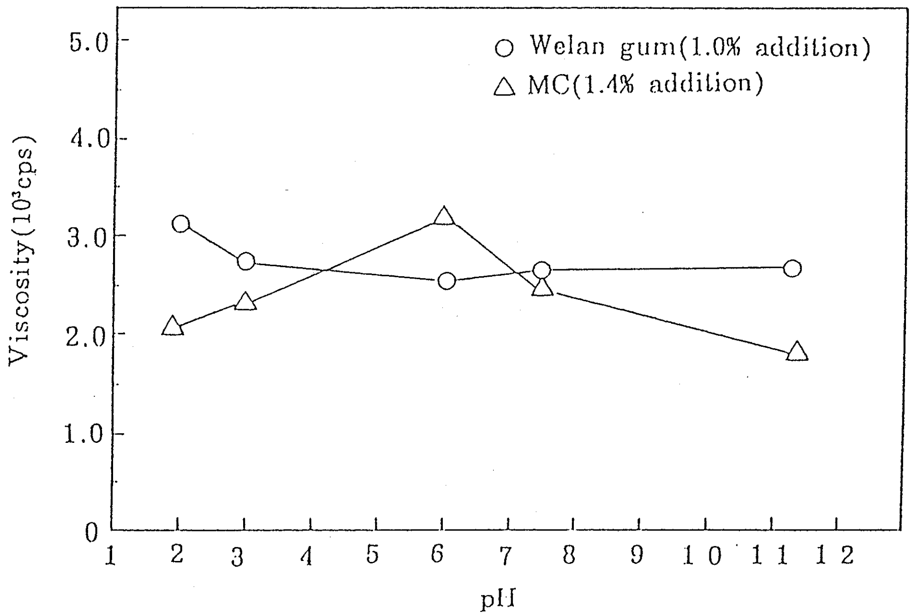


Fig.9. Relationships between viscosity and pH

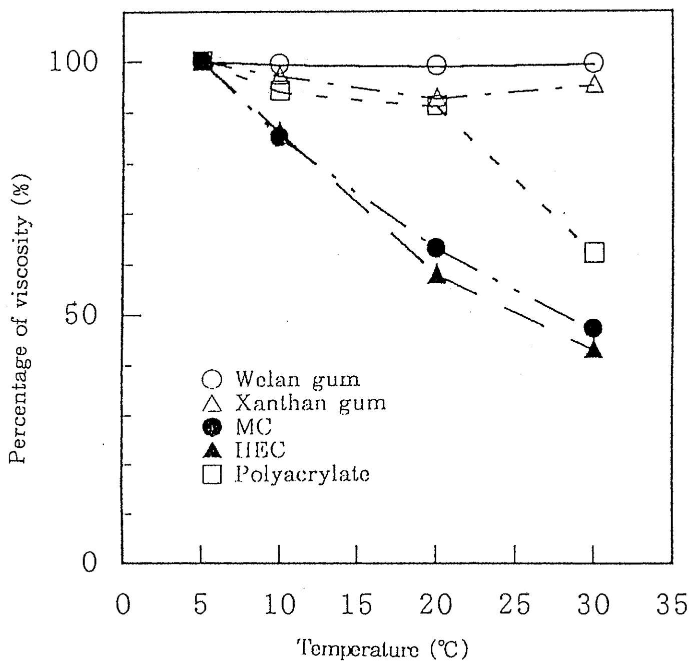


Fig.10. Relationships between viscosity and temperature as a persentage of the value at 5℃

shows the relation between temperature and viscosity as a percentage of the value at 5 ℃. The viscosity of solutions containing Welan gum and xanthan gum are independent of temperature, and these agents develop the same viscosity between 5 and 30℃. This is one of the reasons for the slump flow of highly fluidized concrete containing Welan gum showing little change at different temperatures [12]. In comparison, the viscosity of solutions containing cellulose derivatives or the polyacrylate viscosity agent fell as temperature increased. With regard to the degree of this decrease, solutions with cellulose derivatives fell more in viscosity than those with polyacrylate.

Generally speaking, the viscosity of a solution of water-soluble polymer decreases as the temperature rises. However, no such viscosity change is seen with regard to Welan gum and xanthan gum. This unusual property of xanthan gum was reported by D.A.Ress [13]. He reported that the viscosity of a solution made with distilled water and xanthan gum fell slightly only at the early stages of heating and gradually recovered to its initial value. As to the reason for this phenomenon, he concluded that the structure of xanthan gum molecules in solution might change as the temperature changes. The optical rotation of a xanthan gum solution decreased as the viscosity recovered. Such a decrease in optical rotation indicates a gradual change in structure from a helix to a random coil with hydrodynamics stress. It is thought that a similar phenomenon might also occur in the case of Welan gum.

2.3.3 Relationship between shear rate and viscosity

For an understanding of the relationship between shear rate and viscosity, 1% solutions of each viscosity agent made with the alkaline solution were tested in a rheometer. Figure 11 shows the shear rate versus viscosity as a percentage of the viscosity at a shear rate of 6.6 sec^{-1}. With regard to Welan gum and xanthan gum, the viscosity of the solution decreased sharply as the shear rate increased (pseudoplastic property). This behavior is generally observed in natural polysaccharides, and is thought to be one reason why Welan gum stabilizes the flow properties of highly fluidized concrete. In slump flow tests on highly fluidized concrete containing Welan gum, flow speed gradually slows down after the cone is lifted, and deformational property and viscosity are favorably balanced with the appearance of the pseudoplastic property, resulting in stable flow. Such results have also been obtained at actual construction sites. It is assumed that the deformational property is dominant while the concrete is flowing and that suitable viscosity is developed at the flow front, preventing the concrete materials from separating.

We compared the pseudoplasticity of Welan gum with that of other viscosity agents from the viewpoint of chemical structure. Some reports have mentioned that the side chains of the molecular structure are closely related to pseudoplasticity [14]. Comparing sodium alginate, locust bean gum, and guar gum for example, sodium alginate -- which has no side chains -- exhibits close to Newtonian flow properties, locust bean gum, which has one sugar unit side chain per four or five units of the main chain, has greater pseudoplasticity than sodium alginate, and guar gum, which has one side chain per two units of the main chain, has much greater pseudoplasticity than locust bean gum. Xanthan gum has more prominent pseudoplastic properties than guar gum; it has the same number of side chains per main chain as guar gum, but they are longer than those of guar gum. It is assumed that these longer side chains make it easier for xanthan gum to form super-associative conformation than guar gum due to the twisting of side chains around each other. This associative structure gives a very high viscosity at close to zero shear rate, and then the structure is destroyed by the kinetic energy of a certain shear rate and low viscosity results. In case of Welan gum, it has fewer side chains of almost the same length as guar gum's. But it is assumed that Welan gum has a double-helix or super-associative conformation and thus exhibits the same degree of pseudoplasticity as xanthan gum.

These results indicate that no simple comparison of the pseudoplasticity of solutions of various viscosity agents can be made. Their viscosity is related to the ease with which a super-associative structure is formed as well as number and length of side chains.

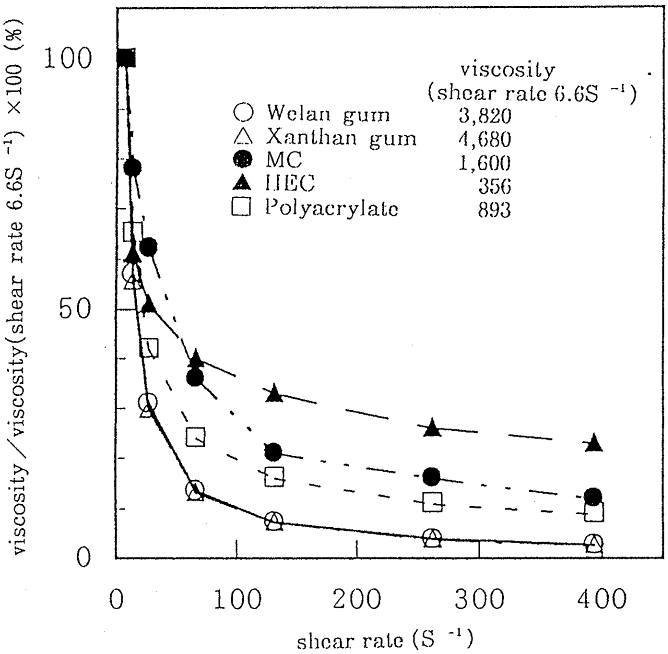


Fig.11. Relationships between viscosity and shear rate

3 EFFECTS ON PROPERTIES OF FRESH CONCRETE

To understand the effects of Welan gum on the condition of fresh highly fluidized concrete, the flow properties, resistance to segregation, flowability in confined spaces, and self-consolidating properties of such concrete were examined experimentally.

3.1 Flow properties, flowability in confined spaces and self-consolidating properties.

It has been reported that a suitable addition of Welan gum to highly fluidized concrete results in stable flow properties as measured by slump flow tests. In this section, the flow properties, flowability in confined spaces, and self-consolidating properties of concrete containing Welan gum are investigated experimentally, including their changes with time.

In tests on the stability of flow properties, five different water contents per unit volume of concrete, -10, -5, ±0, +5 and +10 kg/m^3 of the basic mix proportion, were used to simulate errors in fixing the surface moisture ratio of fine aggregates. These five values represent 155 to 175 kg/m^3 of water content per unit volume of concrete. The materials used in this test and the mix proportion are shown in Tables 3 and 4. This proportion was chosen so as to meet the required characteristics of self-consolidating concrete. The water-powder ratio and gravel content were selected through simple tests so as to achieve a flow time from a V-type funnel test of 15 ±3 cm/s. At W/P=30.2% and G/Glim=55%, the required time was obtained both with and without Welan gum. Even though the viscosity of the concrete was slightly increased by the addition of Welan gum, the degree of this increase was not large because of the very small addition (0.05% of the unit water content). 0.05% and 0.00% of Welan gum to water content were chosen and examined in each test. The addition of superplasticizer was fixed so as to achieve a slump flow of 65 ±1 cm just after mixing, giving a superplasticizer content of 2.5% of the powder content in the case of concrete containing Welan gum and 1.7% without Welan gum. The air content was adjusted to a desirable level by using an air entraining agent. To give a clear picture of the effects of Welan gum, a simple of β-naphthalene sulfonate without a slump-retaining agent such as a retarder was used. The content of fine aggregate was increased or decreased with increasing or decreasing water content.

Table 3. Property of materials

Notation	Name	Specific gravity	Blaine value(cm^2/g)etc.
C	Ordinary Portland cement	3.16	Blaine 3790
SD	Limestone dust	2.70	Blaine 3370
S	Sand	2.69	River sand, Absorption 1.31(%) F.M. 2.69
G	Gravel	2.69	Crushed stone, Max.agg.size 20(mm) Solid Volume 63(%) F.M. 6.61
SP	β-naphtalene sulfonate	—	—
VA	Welan gum	—	
AE	Alkylaryl sulfonate	—	—

Table 4. Mix proportion

Mix No.	Water powder ratio (%)	G/Glim (%)	Slump -flow (cm)	Air content (%)	Unit weight(Kg/m^3) W	C	SD	S	G	SP * (%) (W × %)	VA ** (%) (W × %)	AE * (%) (W × %)
1	30.2	55	65 ±1	4.5±1	165	331	216	713	888	1.7	0.00	0.05
2	30.2	55	65 ±1	4.5±1	165	331	216	713	888	2.5	0.05	0.02

* Caluculated on the basis of (C+SD) weight
** Caluculated on the basis of water weight

In each test, 80 ℓ of concrete was mixed in a 100 ℓ pan-type mixer for 90 sec. Slump flow tests to grasp flow properties, V-type funnel tests to grasp flowability in confined spaces and U-type casting tests for self-consolidating properties were implemented on the fresh concrete, and after 30 minutes and 60 minutes.

The results are shown in Figure 12. In the case of the concrete containing Welan gum, the slump flow just after mixing was from 60.5 to 71.0 cm giving a range of 10.5 cm with different water contents, -10 to +10 kg/m^3. In the case of concrete without Welan gum, the figures were 51.0 to 75.0 cm for a difference of 24.0 cm. This is a bigger range than with Welan gum. With regard to the condition of the concrete, no segregation was observed with Welan gum concrete in any of the cases. By contrast, concrete without Welan gum tended to segregate with, for example, floating paste appearing on the surface of the concrete, when the water content was +5 and +10 kg/m^3. In concrete containing Welan gum, the slump flow 30 min. and 60 min. after mixing was almost unchanged with ±0, +5, +10 kg/m^3 water content, and flow properties did not deteriorate. The slump flow of concrete with Welan gum had a tendency to decrease with water contents of -5, -10 kg/m^3. But even with -10 kg/m^3 of water content, the slump flow was more than 50 cm.

The slump flow of concrete without Welan gum did not decrease with water contents of +5 and +10 kg/m^3, because segregation occurred just after mixing in these systems. On the contrary, at 60 min. after mixing these concretes exhibited no segregation and became excellent flowable concrete. With -5 and -10 kg/m^3, slump flow degraded considerably as time passed.

From these results, it can be concluded that the addition of Welan gum minimizes changes in flow properties due to variable water content and has the effect of maintaining stable flowability. The reasons for these effects will be examined in section 3.3 in detail.

The second layer of Figure 12 shows the average velocity as calculated from time measurements of outflow through the V-type funnel. Concrete containing Welan gum tended to be slower with lower water content and as time passed. However, the change was comparatively small, from 7.0 to 16.9 cm/s. The change in the case of concrete without Welan gum was large, 6.5 to 27.5 cm/s, in the case of a slump flow of more than 70 cm. This is because low viscosity and segregation cause the concrete to flow suddenly or to flow slowly owing to interference among coarse aggregate particles. When the slump flow was less than 50 cm, the velocity was extremely low or the concrete was unable to flow out at all due to a blockage in the funnel.

The lowest layer of Figure 12 shows the results of U-type casting tests. The height of the casting made with concrete containing Welan gum was more than 30 cm in all cases for water contents of -10 to +10 kg/m^3, and at all ages, initial, 30, and 60 minutes after mixing. These results mean that a concrete system containing Welan gum has excellent consolidating properties. The height of the casting was 31.0 cm in the case of the concrete with a water content of -10 kg/m^3 and left for 60 minutes after mixing, despite the small slump flow of 51.0 cm. This means that Welan gum provides suitable viscosity while improving the consolidating properties, even in the case that the deformational property is weak. The casting height of concrete without Welan gum was small, because of interference among coarse aggregate particles in the case of too large a slump and lack of deformational property in the case of too small a slump flow. The peak of the casting height of concrete without Welan gum occurred with higher water content as time passed. This is because the change in slump flow with the passage of time was rather large and the most suitable consolidating properties

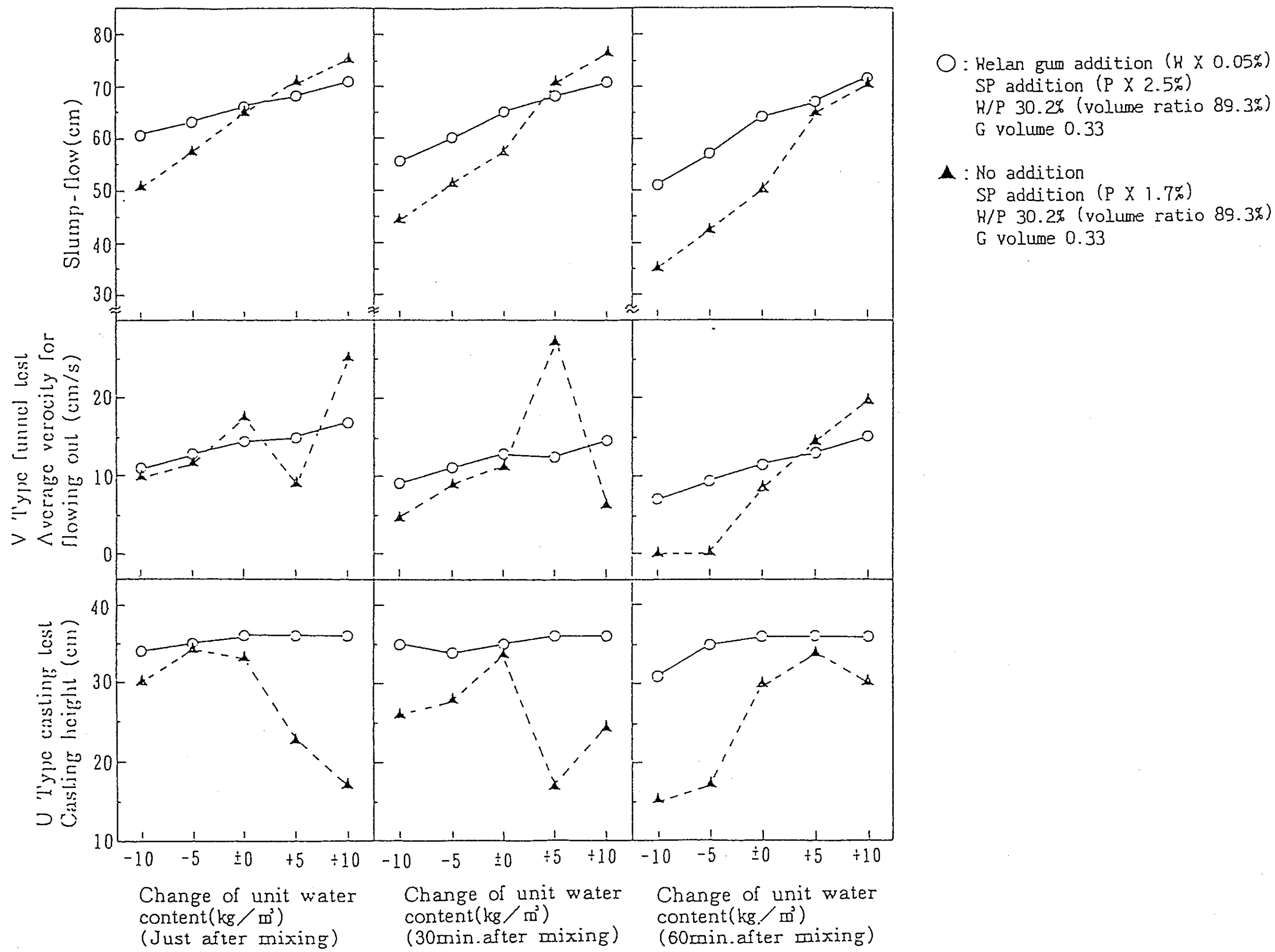


Fig.12. Change of property of fresh concrete

arose coincidentally at that time

From the three results obtained just after mixing, it can be concluded that the casting height of concrete with Welan gum is higher than that without Welan gum, in spite of similar slump flows. Thus the use of Welan gum contributes to improved self-consolidating properties.

These experiments teach us that the addition of a suitable dosage of Welan gum stabilizes fluidity, increases flowability in confined spaces, and provides excellent self-consolidating properties over a wide range of slump flow.

3.2 Resistance to segregation

The segregation of in highly fluidized concrete not only takes the form of segregation of mortar and coarse aggregates, but also separation of a water-like paste on the surface of the concrete caused by the large amount of superplasticizer needed to obtain high flowability. This latter form of segregation causes blockages during the pressurized delivery of concrete by pump, and it often occurs when material quality is variable, quantity measurements have errors, and the temperature varies. There is as yet no simple method of evaluating such segregation quantitatively.

In this section, the authors suggest a simple method of measuring such segregation and use it to evaluate the effects of Welan gum on segregation.

3.2.1 Method of evaluation

We have developed on evaluation method for segregation as caused by the addition of large amounts of superplasticizer. Figure 13 shows the apparatus. A sample is stuffed into a light mold (ϕ10cm×20cm), the surface is flattered with a straight edge, covered with kitchen paper, and then capped with a cell-plate over the paper. Highly fluidized concrete or highly fluidized mortar samples can be tested. After leaving a sample for four minutes, the weight of the kitchen paper is measured. Embossed kitchen paper of thickness 0.28 to 0.35 mm and with an absorption of 1.5 sec. (according to JIS S 3104), and which is made of 100% pulp, is used. The paper sheets are 114 mm ×112.5 mm. The viscosity of the paste adhering to the paper is quite low, and it is different from bleeding.

3.2.2 Testing and examination of the effects of Welan gum

An initial evaluation was carried out on mortar specimens. Materials and the mix proportion of samples used to evaluate the new method are shown in Tables 5 and 6. The ratios of Welan gum to water content were 0.0%, 0.02%, and 0.05%, and the amount of superplasticizer was varied as shown in Table 4. Mortar was mixed in a Hovert mixer of capacity 11.4 ℓ. Fine aggregates, cement, Welan gum, and the mixture of water and superplasticizer were added in that order and agitated at low speed (106 rpm) for one minute, at medium speed (196 rpm) for one minute and at high speed (358 rpm) for three minutes for a total of five minutes agitation. A mortar flow test was carried out immediately after mixing and the new evaluation of segregation then implemented. Figure 14 shows the relationship between amount of superplasticizer and the weight of paste on the paper, as well as the relationship between amount of superplasticizer and mortar flow. The three ratios of Welan gum are shown. In the figure, a ○ mark means that no segregation was observed, ● means that segregation was evidenced by the existence of floating paste, and ◑ means there was slight segregation. The

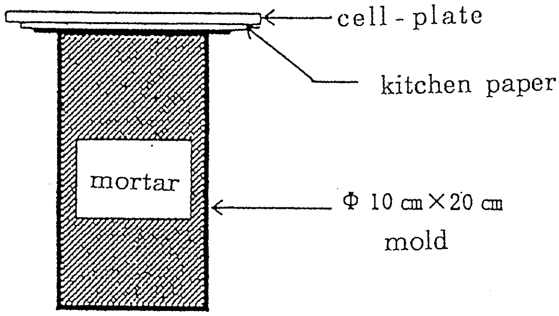


Fig.13. Test equipment for segregation property

Table 5. Properties of materials

Notation	Name	Specific gravity	Blaine value(cm^2/g)etc.
C	Ordinary Portland cement	3.16	Blaine 3700
S	Sand	2.52	River sand, Absorption 1.61(%) F.M. 2.68
W	Water		Tap water
SP	β-naphtalene sulfonate	—	—
VA	Welan gum		

Table 6. Mix proportion of mortar

Mix No.	W/C (%)	S/C	Unit weight(Kg/m^3) W	C	S	VA * (%)	SP ** (%)
1	30	0.8	323	1072	855	0.0	2.0 ~6.9
2	30	0.8	323	1072	855	0.02	2.0 ~6.0
3	30	0.8	323	1072	855	0.05	2.0 ~9.0

* Caluculated on the basis of water weight
** Caluculated on the basis of (C) weight

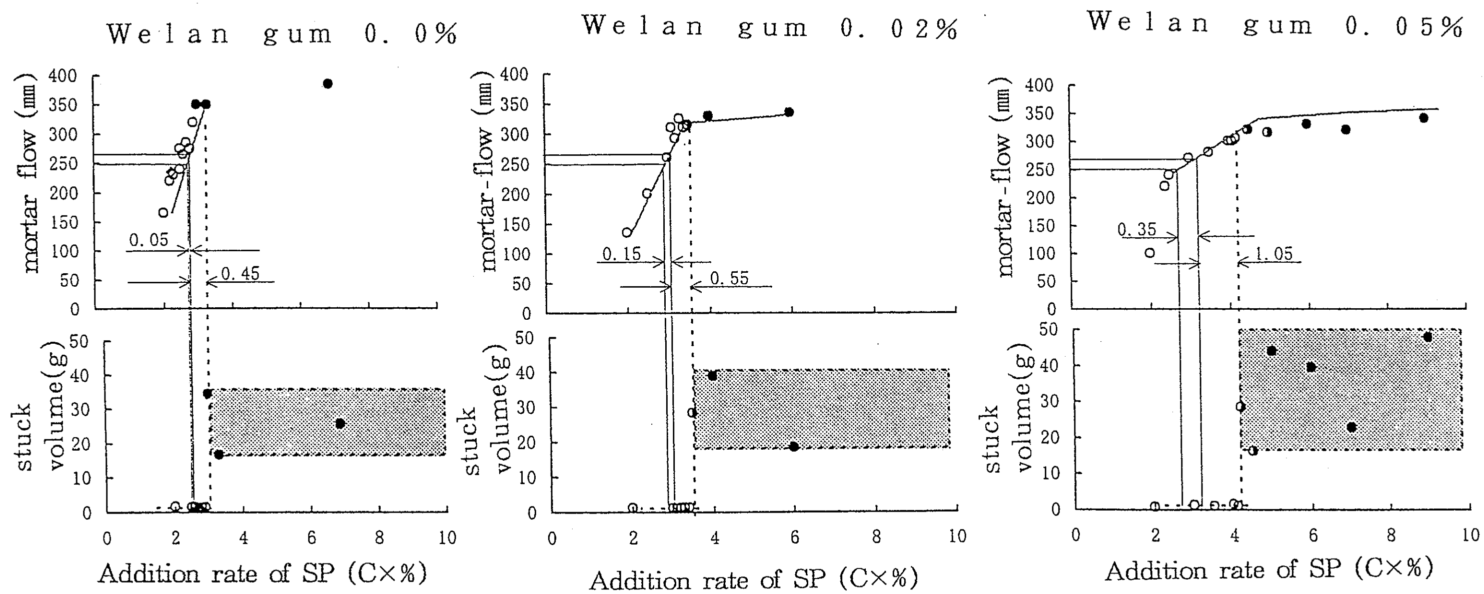


Fig.14. Relationships between mortar flow, weight of paste on the paper and amount of SP

figure shows that the weight of adhered paste increased rapidly at a certain level of superplasticizer regardless of the amount of Welan gum. There was good correspondence between these test results and observations by eye. Segregation was clearly observed with superplasticizer levels higher than the point at which rate the adhered weight increased rapidly. However, in the case without Welan gum, this change point was very distinct, while with Welan gum it was somewhat less clear.

From these results, we conclude that segregation resulting from addition of a superplasticizer can be evaluated almost quantitatively by our suggested method. After the evaluation using mortar, we carried out tests with highly fluidized concrete containing Welan gum. As shown in Figure 15, the turning point in the amount of segregation rises as the amount of Welan gum is increased. The ideal addition of superplasticizer to obtain highly fluidized concrete with a mortar flow of 250 to 270 mm was 0.05% at 0.0% Welan gum, 0.15% at 0.02% gum, and 0.35% at 0.05% gum, as shown in Figure 14. The range of ideal addition rate of superplasticizer became wider as the increase of Welan gum's addition. In other words, the change of mortar flow became smaller to the change of the rate of the superplasticizer.

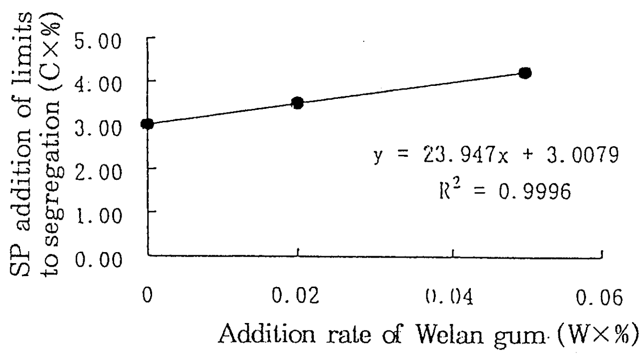


Fig.15. Relationships between SP addition of limites to segregation and Welan gum addition

The difference between the ideal addition of superplasticizer and the turning point became greater as Welan gum was added. This means that the addition of Welan gum can help to produce safer highly fluidized concrete as regards the segregation of materials.

3.3 Maintaining flowability

In the experiment above, we determined that the addition of Welan gum limits changes in flowability as time passes. In this section, we examine the mechanism by which flowability is maintained. In particular, we investigate the point of interaction between Welan gum and the superplasticizer through the mortar tests.

The mortar materials used in this test are shown in Table 7. Welan gum was added as 0.2% of water solution because of its very small addition rate. The mortar was made by placing 321g. of cement, 216g. of limestone powder, 710g. of fine aggregates, and 175g. of water (including superplasticizer and Welan gum), in that order, into the mortar mixer. This mix was agitated at low speed (63 rpm) for one minute and at high speed (126 rpm) for two minutes for a total of three minutes.

Table 7. Property of materials

Notation	Name	Specific gravity	Blaine value(cm^2/g)etc.
C	Ordinary Portland cement	3.16	Blaine 3400
SD	Limestone dust	2.71	Blaine 3300
S	Sand	2.57	Mountain sand, Absorption 1.60(%) F.M. 2.89
SP	β-naphtalene sulfonate	—	—
VA	Welan gum	—	

The viscosity of gum solution and the solution with superplasticizer, change of static flow as time passing on mortar test and quantity of superplasticizer absorbed were measured. Regarding absorption, we measured the amount of superplasticizer in water separated by 15 minutes in a centrifuge at 3,000 rpm by UV spectrum analysis, and calculated the difference between the amount added and that found as a residue in the separated water. As regards viscosity, we measured 100g of a solution containing 10g of superplasticizer, the prescribed quantity of Welan gum, and the prescribed amount of water using a B-type viscometer at 30 rpm.

Static flow of the mortar was adjusted in the range of 260±10 mm by changing the amount of superplasticizer and measured it every 15 minutes after initial mixing, as shown in Figure 16. As the figure shows, the amount of superplasticizer needed to obtain the initial static flow (260 mm) increased as more Welan gum was added. In this test, no segregation resulting from the high level of superplasticizer was observed in any case. We assume that Welan gum has some kind of restricting effect on the superplasticizer. In order to examine the interaction between Welan gum and superplasticizer, the viscosity of two solutions was measured: one was a simple Welan gum solution and the other was a superplasticizer solution with Welan gum, as shown in Figure 17. A 10% superplasticizer solution with Welan gum was less viscous than a simple Welan gum solution. Since the viscosity of a 10% simple superplasticizer solution was 3.6 cps, the effect of its viscosity is negligible. Regarding the decrease in viscosity when superplasticizer coexists with Welan gum, we conclude that the apparent proportion of Welan gum in the solution is reduced when it forms a restricted product of low solubility with the superplasticizer. For this reason, it is assumed that the dispersing ability of the superplasticizer might fall as a result of this restricted amount of Welan gum, and thus segregation is controlled.

Figure 18 shows the relationship between the amount of Welan gum and the amount of superplasticizer absorbed, and also the amount of Welan gum and the residual quantity of superplasticizer. As the figure shows, the superplasticizer residue was a maximum at around 0.05% of Welan gum in the case of 2.6% superplasticizer, and thus the amount absorbed was minimized there. We reason that the absorbed amount of superplasticizer is the sum of that absorbed by the cement and the quantity restricted by reaction with Welan gum. The degree of restriction by Welan gum determined the quantity that was extracted by the centrifuge treatment, so this quantity of superplasticizer was taken to be the quantity of residue in this test. As the Welan gum addition increases, it obstructs the absorption of

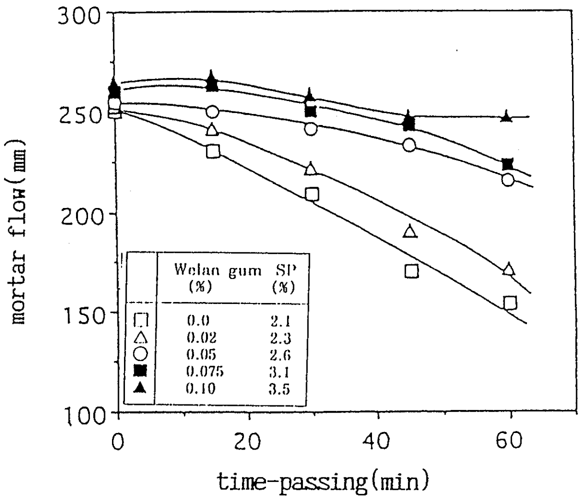


Fig.16. Relationships between mortar flow and time passing

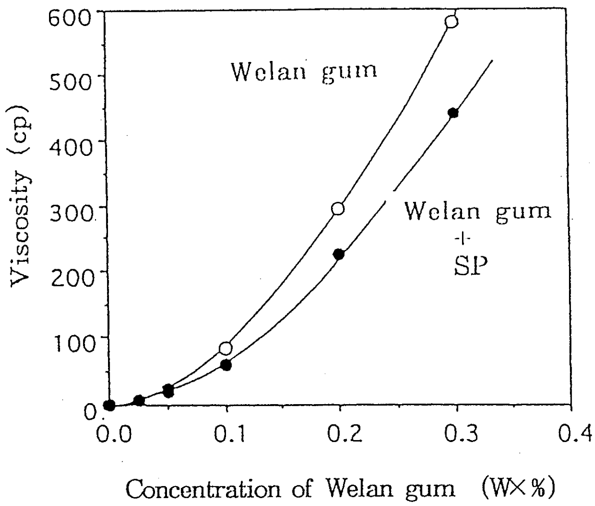


Fig.17. Relationships between viscosity and concentration of Welan gum

superplasticizer by the cement to some degrees, and also weakly restricts the superplasticizer according to the understanding of Figure 18. This force is not very strong, so it controls the segregation of mortar but separation is easy with a centrifuge. The superplasticizer residue thus increases as more Welan gum is added. The part of the superplasticizer restricted by the Welan gum is left gradually to the system, and contributes to the dispersion of cement; this is so-called retarding property. At some higher additions of Welan gum, the superplasticizer is restricted by a stronger force, the residue decreases, and the flowability of the concrete is influenced. This turning point in addition Welan gum depends on the amount of superplasticizer, and there is an ideal proportion of Welan gum and superplasticizer.

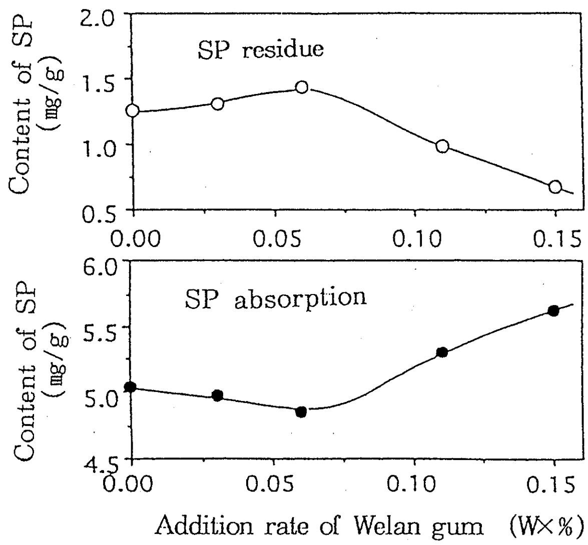


Fig.18. Relationships between SP residue, SP absorption and Welan gum addition

4. CONCLUSION

Through experimental examinations of typical properties of the viscosity agent Welan gum, the effects of Welan gum on the fluidity of highly fluidized concrete, flowability in confined spaces, and self-consolidating properties were investigated in detail. The results are summarized below.

(1) Welan gum solution yields almost constant viscosity regardless of the calcium content (0 to 10%) or pH (2 to 12) except for a slight increase under alkaline conditions. This characteristic is unique and is not seen with cellulose-based derivatives and polyacrylate viscosity agents.

(2) The viscosity of a Welan gum solution remains substantially unchanged within the temperature range 5 to 30℃. This is why the change in slump flow of highly fluidized concrete containing Welan gum is small at different temperatures.

(3) Welan gum solution offers very high viscosity at rest and low viscosity at high shear rates (pseudoplastic property). This characteristic is assumed to derive from the number and length of the side chains in its chemical structure, as well as the ease with which it takes up a super-associative structure.

(4) The addition of 0.05% Welan gum not only offers stable fluidity and good flowability in confined spaces, but also gives highly fluidized concrete excellent self-consolidating properties to over a wide range of slump flow (50 to 70 cm).

(5) We suggest a simple, quantitative method of evaluating segregation resulting from high addition of superplasticizer. In this method, kitchen paper is placed on the surface of fresh concrete or mortar for a few minutes, and the weight of the paper plus adhering paste is measured.

(6) The addition of Welan gum increases the turning point in segregation large with the addition of superplasticizer, gives greater leeway between the ideal addition and this turning point, and makes the resulting highly fluidized concrete safer as regards segregation.

(7) If Welan gum is added, more superplasticizer is required. However, the interaction between Welan gum and superplasticizer provides highly fluidized concrete with stable flowability as time passes.

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