A Study on Characteristics of Urethane Polymer as Injection Material for Ground Improvement

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요　지

본 연구에서는 케미칼 그라우팅용의 폴리우레탄계 2성분 주입약액 및 그의 반응고결물인 발포고결체의 물리적, 화학적 성질에 관하여 조사하였다. 이들의 성질을 좌우하는 요소들을 규명키 위한 실험결과, 폴리우레탄계 주입약액 및 그의 고결생성물의 물리적, 화학적 거동은 토질의 상태 즉, 온도, 함수비 및 흙의 밀도 등과 같은 주입대상지반의 조건에 의해 크게 영향받는 것을 알 수 있었다. 또한, 폴리우레탄계 약액그라우팅의 지반보강효과 및 차수효과를 검증키 위해 현재 건설중인 지하철등에서의 터널 굴착시의 폴리우레탄계 약액주입 시공예를 중심으로 그 효과를 조사하였다.

주요어 : 주입재, 지반보강, 차수, 폴리우레탄

Abstract

The physical and chemical properties of polyurethane-yieding two-component liquid injection mixture and those of the resulting polyurethane solid foam for chemical grouting are investigated. The chemical experiments on the factors influencing the properties of polyurethane show that the behaviors of polyurethane-yielding liquid material and those of the produced polyurethane solid foam are greatly affected by the ground conditions such as temperature, water content and density of soil. The ground reinforcing and water-blocking effects of polyurethane grouting are examined through field case history of tunnel excavation of the subway under construction.

Keywords : Injection material, Ground improvement, Water-blocking, Polyurethane

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1. Introduction

The chemical grouting method using polyurethane as injection material for improvement and reinforcement of the ground has often been used in underground construction works because this method is considered effective and convenient in comparison with other substitutional methods(Chun, B.S. et al., 1993). The polyurethane grouting is based on three dimensional networked solid polymer with high strength that is produced with generation of heat and increase of volume when liquid isocyanate compound is mixed with a liquid polyol compound which contains little amount of water(Ulrich, H. 1982 ; Wolf, H.W. 1956 ; Wood, G. 1982). Therefore, technical information on the chemical and physical behaviors of the liquid injection material and those of the polyurethane solid foam are supposed to be very important for an effective application of this grouting method.

In this study, the chemical and physical properties of the liquid injection material and the resultant polyurethane solid foam and the internal and external factors influencing them are investigated.

2. Characteristics of Polyurethane Injection Material

2.1 Principles of Polyurethane Formation

Polyurethane is a chemical name of a polymer which contains carbamate groups (−NHCOO), also referred to as urethane groups, in their backbone structure. Polyurethane is obtained by the reaction of a diisocyante with macroglycol, a so-called polyol, or with a combination of a macroglycol and a short chain glycol extender. In the latter case, segmented block copolymer is produced. The macroglycols are based on polyethers, polyesters, or a combination of both. A linear polyurethane polymer has the structure(1) shown below, whereas a linear segmented copolymer obtained from a diisocyanate, a macroglycol, and ethylene glycol has structure(2) shown below.

$$-RO\overset{\overset{O}{\|}}{C}NHR'NH\overset{\overset{O}{\|}}{C}O-$$

Structure(1)

$$-RO\overset{\overset{O}{\|}}{C}NHR'NH\overset{\overset{O}{\|}}{C}OCH_2CH_2O\overset{\overset{O}{\|}}{C}HNHR'NH\overset{\overset{O}{\|}}{C}O-$$

Structure(2)

In addition to the linear thermoplastic polyurethanes obtained from difunctional monomers, branched or cross-linked thermoset polymers are made with higher functional monomers. Linear polymers have good impact strength, good physical properties, and excellent processability, but owing to their thermoplasticity, thermal stability is limited. Thermoset polymers, on the other hand, have higher thermal stability but lower impact strength. The higher functionality is obtained with higher functional isocyanate, so-called polymeric isocyanates, or with higher functional polyols. Cross-linking is also achieved by secondary reactions. For example, urea groups are generated in the formation of water blown flexible foams. An isocyanate group and water yield an amino group which immediately reacts with excess isocyante to form urea linkages. This reaction is accompanied by the evolution of carbon dioxide, which acts as a blowing agent. Further reaction of the urea group with the isocyanate leads to cross-linking via a biuret group. Water-blown flexible and rigid foams contain urethane, urea, and some biuret groups in their network structure. The overall reactions are shown below.

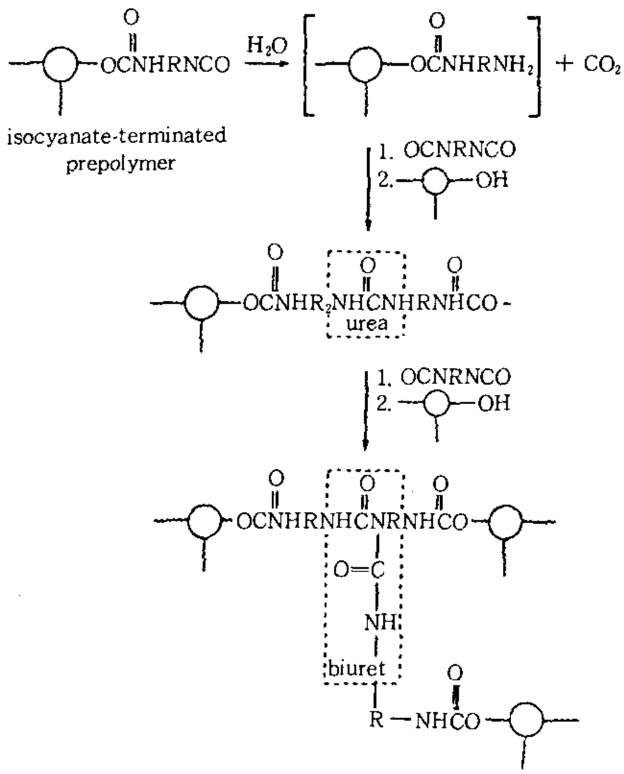

Fig. 1 Overall reactions

2.2 The Relationship between Temperature and the Viscosity of Injection Material (Polyurethane-yielding Liquid Mixture)

The experimental relationship between the viscosity of polyurethane-yielding liquid injection material and temperature is shown in Fig. 2.

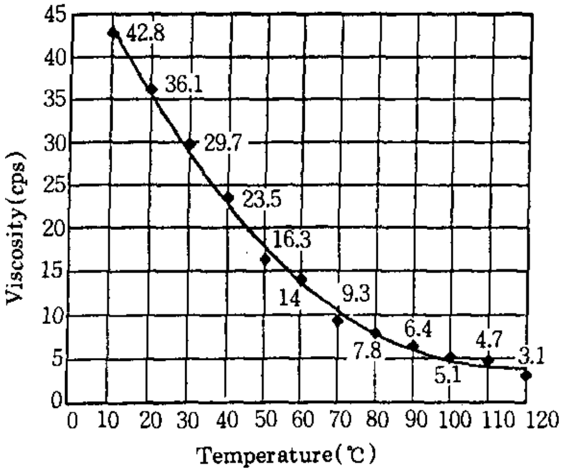

Fig. 2 Relation between temperature and viscosity

The viscosity of the injection material, which is about 40 centipoise per second(cps) at room temperature, sharply decreases with the rise of temperature and drops below 10cps at approximately 70℃.

The temperature vs. time relation of the injection material is shown in Fig.3. Much heat is generated with the reaction, and the temperature of the injection materal rises to the vicinity of 100℃ in approximately 60 seconds before the gelation of the material.

Fig.4 shows the presumed viscosity variation of injection material with the lapse of time, which is obtained by combining Fig. 2 and Fig. 3.

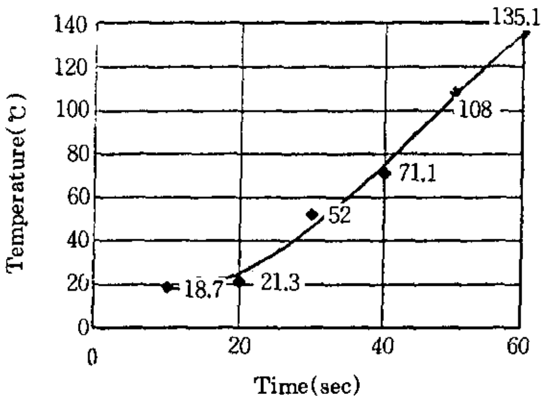

Fig. 3 Relation between reaction time and temperature

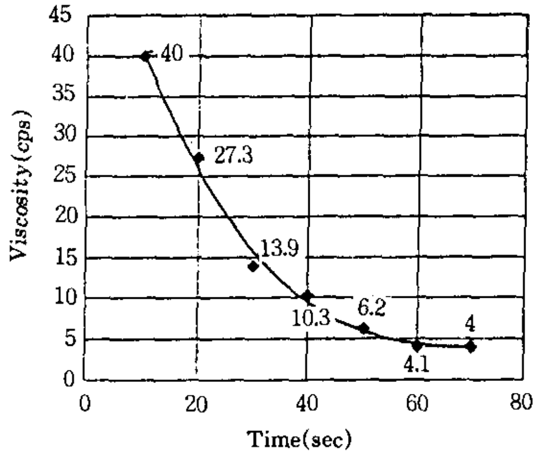

Fig. 4 Presumed relationship between reaction time and viscosity of injection material.

Based on the above results, the viscosity of the injection material during the injection process becomes much lower(below 10 cps) than the initial viscosity. This result implies that permeability of the injection material may be improved if the viscosity is closely controlled.

2.3 Effect of Water in the Injection Material on the Properties of Polyurethane Foam

Properties such as foaming ratio and mechanical strength of polyurethane foam depend on the amount of water in the liquid-state injection material. The relationship between foaming ratio and the amount of water added to the original polyurethane-yielding liquid injection material under atmospheric pressure is shown in Fig.5.

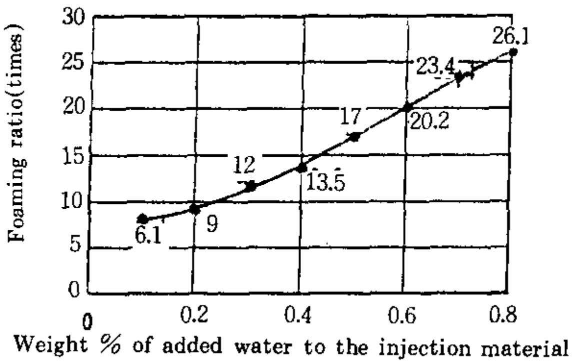

Fig. 5 Relationship between foaming ratio and amount of added water

Within the specific range, foaming ratio increases in proportion to the amount of water added. Compression strength values of each polyurethane foam samples obtained from the above foaming test are shown in Table 1.

Table 1. Compression strength of polyurethane foams.

Foaming ratio(times)	8	10	12	14	16	18
Compression strength(kgf/cm^2)	21.5	15.3	11.3	8.7	6.2	4.9

The decrease in the mechanical strength as the foaming ratio increases is much larger than expected. This means that water-evolved polyurethane foam having high foaming ratio has looser inner structure than the simple expanded foam. This needs to be considered when polyurethane grouting is injected into wet ground.

2.4 Effect of External Pressure on Foaming Ratio of the Injection Material

Foaming ratios of polyurethane-yielding injection material under the various pressures are shown in Table 2. The foaming ratio linearly decreases as external pressure increases.

Table 2. Foaming ratios of injection material with the variation of pressures.

Pressure(atm)	1	2	3	4
Foaming ratio(times)	8.5	4.3	2.6	1.8

2.5 Experimental Investigation

Ultrathane-SRU(commercial name) is used as polyurethane-yielding two-component injection material. To accomplish the foaming test, main component(A) and hardener(B) were mixed with the ratio of 1:2.5(by weight) and then stirred at the speed of 1,000rpm for 10 seconds. Viscosity was measured by Brookefield LVT viscometer. Mechanical strength was measured according to the KS M3809-92 test method.

3. A Case Study of Application(Lot ○○ of Seoul Subway Route)

3.1 Geological Setting of The Tunnel Ground(B.S. Chun, 1995)

The thickness from the top of the tunnel to the ground surface is 25 meters. The thickness of weathered rock layer from the tunnel crown is 17 meters upward and from the bottom of the tunnel is 5 meters downward. The condition of weathered rock is poor. RMR of ground that the tunnel passes through is less than 30. Weathered rock, when examined with naked eyes, has many tiny joints and extreme effluence of underground water.

3.2 Injection Condition of Polyurethane

According to the equation for improving thickness, the injection amount per each hole is about 74kg. Basically, the injection pressure is 5~30kg/cm^2, the injection range is 60 degree, improving thickness is 2.0 meters, the pitch of injection holes is 60 centimeters, and the length of injection holes is 3.0 meters. Various injection conditions, however, are applied according to the ground state.

3.3 Laboratory Tests

3.3.1 Unconfined Compression Test

As the result of unconfined compression test, uniaxial strength of samples is 7.0~103.5 kg/cm^2, and the deformation modulus is 2.4×10^3~22.0×10^3kg/cm^2. In case of a similar sample, the uniaxial strength of urethane reinforced one is improved by 84kg/cm^2 compared to the original value, 35kg/cm^2.

3.3.2 Permeability Test

Table 3. Summary of permeability test

	permeability (cm/sec)	sample size(cm^3) (width×length×height)	state of urethane injection	note
No.1	3.2×10^{-6}	(4.8×4.5×4.6)	not injection	relative intact
No.2	7.1×10^{-7}	(5.0×5.1×4.9)	injection	relative intact
No.3	1.1×10^{-5}	(5.0×5.0×5.4)	partly injection	severly fractured, partially injected
No.4	1.8×10^{-3}	(4.7×4.5×5.1)	not injection	severly fractured, leaks from joint

According to the ground investigation, the permeabilities of weathered rock were 8.04~3.43$\times10^{-3}$cm/sec. But after urethane injection, it is confirmed by laboratory test that permeabilities are decreased as seen in table 3.

3.4 Effect of Urethane Injection by Numerical Analysis

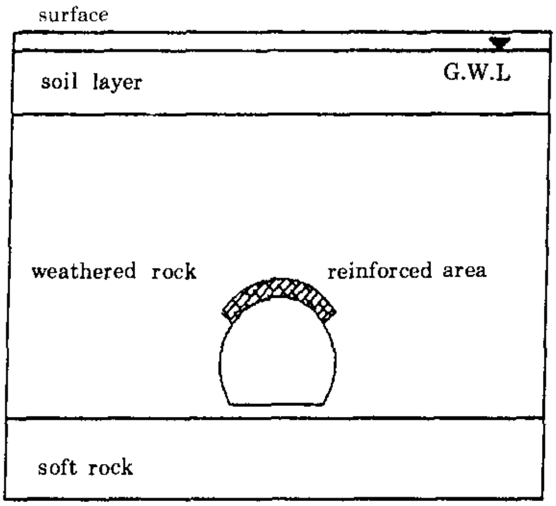

Fig. 6 Analytical section of urethane reinforced ground

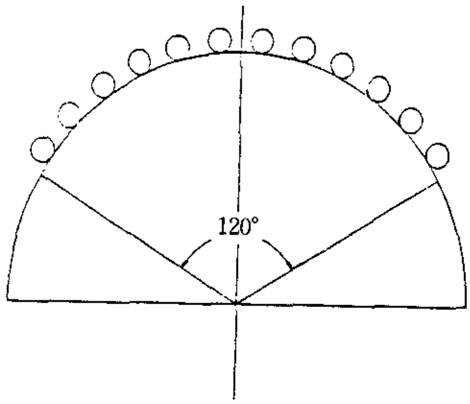

Fig. 7 The standard diagram of urethane reinforced tunnel

(a) The effect of displacement reduction at tunnel crown by urethane injection method is analyzed in both cases of original tunnel and urethane reinforced tunnel. At 2K506, the maximum settlement is 5.353mm in the original tunnel and 2.002mm in the urethane reinforced tunnel. And at 2K400, the maximum settlement is 4.718mm in the original tunnel and 1.818mm in the urethane reinforced tunnel. The analytical settlement in urethane reinforced tunnel by numerical analysis is 7.9mm. The reinforcement effects are 62.60% at 2K506 and 61.47% at 2K400. Fig. 8. shows the variation of settlement at tunnel crown.

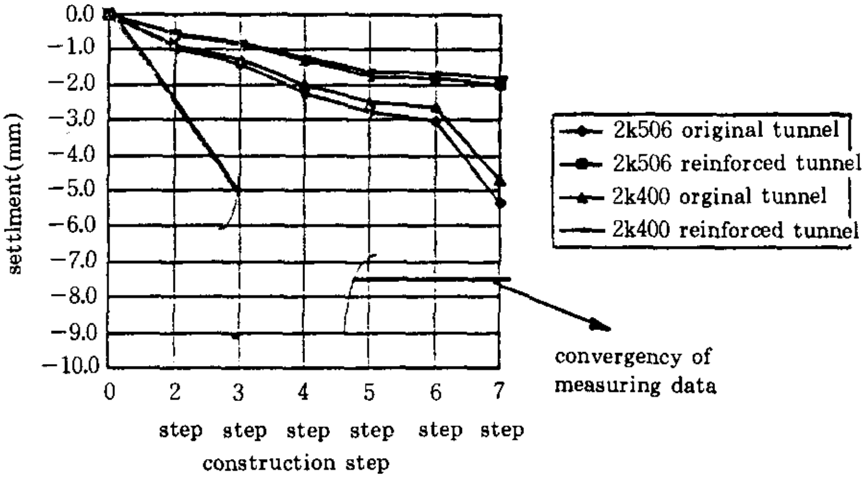

Fig. 8 The comparision of settlement at tunnel crown

(b) The variation of displacement before and after urethane injection is shown in Fig.9. As a result of reducing effect of urethane grouted tunnel, the displacement of the left side wall at 2K506 is reduced from 6.847mm to 6.686mm. The improvement effect is 16.9%. And the displacement of the right sidewall is reduced from 6.762mm to 5.93mm. The improvement effect is 12.3%. The displacement of the left side wall at 2K400 is reduced from 5.686mm to 2.229mm. The improvement effect is 60.8%. The displacement of the right side wall is reduced from 5.931mm to 2.388mm. The improvement effect is 59.7%.

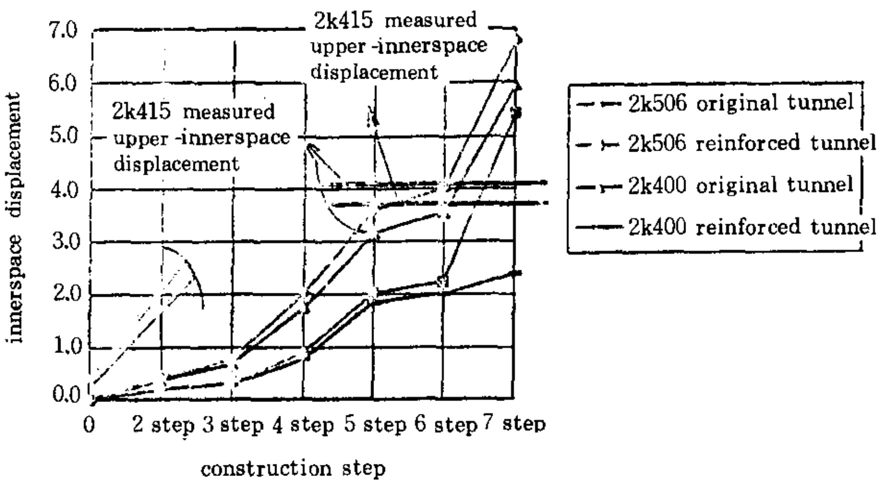

Fig. 9 The reducing effect of displacement by urethane injection(left side wall)

(c) The settlement of ground surface at 2K506 is 2.969mm in the original tunnel, 0.940mm in the urethane reinforced tunnel and the improvement effect is 68.3%. In 2K400, the settlement is 2.072mm in the original tunnel, 0.844mm in the urethane reinforced tunnel and the improvement effect is 57.3%.

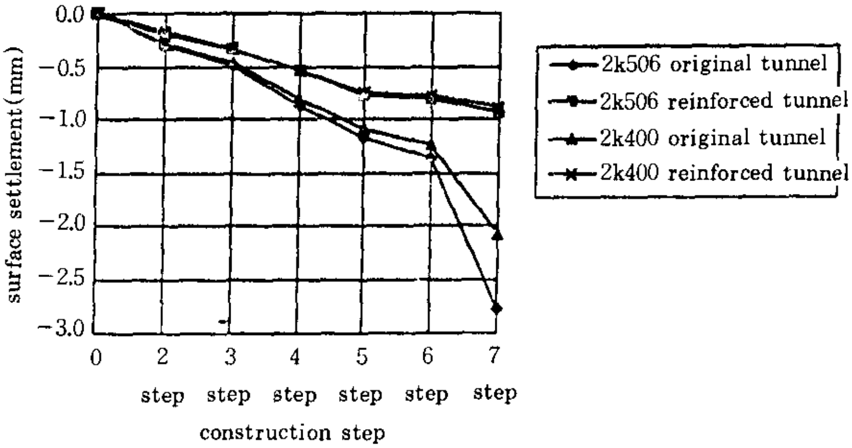

Fig. 10 The reducing effect of settlement of ground surface by urethane injection

4. Conclusions

The properties of polyurethane-yielding injection material and the resulting polyurethane solid foam are very versatile and with close control, polyurethane grouting can be more effectively and successfully applied to many other construction projects. Variations of the design parameters are scrutinized by performing the laboratory test with construction sequency(multi-stage excavation, shotcrete & rock bolt installation, etc). Also, the effectiveness of polyurethane grouting method may be examined by parametric study of design parameters using numerical analysis.

By carrying out this construction project on polyurethane grouting, following results are obtained. First, the improvement of cut-off effect and the increase of unconfined strength may be examined in a laboratory test. Second, the outstanding effects of displacement-reduction around urethane injected tunnel may be examined by numerical analysis.

Acknowledgements

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References

1. Chun, B.S.(1995), "A study on the tunnel ground reinforcement in construction lot ○○ of the Seoul Subway Route ○○", Research Institute of Construction, Hanyang University, pp.122~161.
2. Chun, B.S., Kim, S.S., Park, H.K. and Chang, M.S.(1993), "A Study on Behaviour of Coal Ash for Embankment and Pavement Materials", Korea Science and Engineering Foundation(KOSEF), pp.73~178.
3. Ulrich, H.(1982), *Introduction to Industrial Polymers*, C.Hanser & V.Munchen, FRG, pp. 56~79.
4. Wolf, H.W.(1956), "Catalyst Activity in One-shot Urethane Foam", Technical Bulletin, Dupont, Wilmington, pp. 30~65.
5. Wood, G.(1982), *Flexible Polyurethane Foams. Chemistry and Technology*, Applied Science Publishers, London, pp. 120~160.

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