화약 · 발파(대한화약발파공학회지)
제38권 제4호, 2020년 12월, pp. 46~52

EXPLOSIVES & BLASTING, Vol. 38, No. 4, 2020, pp. 46-52
https://doi.org/10.22704/ksee.2020.38.4.046

Anti-washout Grouts for Underwater Sealing of Karst Cavities and Construction Research Tendencies

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수중 불분리성 그라우트 개발 기술 동향

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Abstract Although anti-washout grouts are used extensively in underwater targets, major constraints continue to be associated with their use. These include poor bonding strength, poor pumpability, and loss of high strength in everyday engineering applications. In this study, based on the literature pertaining to self-compacted, non-dispersive, anti-washout grouts, a review of research trends in anti-washout grouts for underwater construction and sealing of karst cavities was carried out in order to determine the problems faced in this field. Grouts used under water suffer a loss of strength and bonding strength in comparison to grouts cast in air. Researchers are designing high-viscosity grouts to overcome the inrush of water and seal karst cavities; however, in doing so, they have inadvertently caused serious problems pertaining to the pumpability of these grouts and concretes in deep target locations. Thus, the majority of the anti-washout grouts and concretes that have been developed are not applicable to deep target environments, instead being suitable for only near-surface targets.

Key words Anti-washout cement grouts, Anti-dispersity, Underwater construction, Anti-washout admixtures (AWAs)

초 록 수중 불분리성 그라우트는 수중 현장에 광범위하게 사용된다. 그러나 접합강도, 펌프 능력 및 강도 손실과 같은 주요 문제점이 여전히 존재한다. 본 연구에서는 자기충전, 비파괴 방지 그라우트 연구에 기초하여 이 분야의 현황을 파악하기 위해 수중 시공 및 카르스트 공동 실링에 관한 연구 동향에 대해 검토하였다. 그라우트를 수중에 사용할 경우, 공기 중에서 시공하는 것에 비해 강도와 접합강도가 손실될 것이다. 이를 방지하기 위해 고점도의 그라우트를 통해 카르스트 공동을 실링하고 있지만, 대심도에서는 그라우트의 펌핑 능력에 심각한 문제를 발생시키므로 기존의 수중 불분리성 그라우트와 콘크리트는 대심도 환경에 적합하지 않음을 의미한다.

핵심어 수중 불분리성 그라우트, 비분산, 수중 시공, 워시 아웃 방지 혼합물

1. Introduction

In recent years, an increasing number of problems regarding grouting, including the washout of concrete due to dispersion, have emerged. A high flow of water and the steady movement of groundwater cause finer particles of cement to be washed away through cracks and joints. To mitigate this problem, various techniques are currently being used. One example of such a technique is the tremie method, in which the desired area is covered with a casing and concrete or grout is pumped through a pipe from lower to higher levels. This prevents or minimizes contact with water

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게재 승인일 : 2020년 12월 18일

and, therefore, reduces dispersion (Hunicke, 1951). The real challenge becomes apparent when considering the grouting of deep subsurface targets, such as cavities. Grouting of deep subsurface targets is complex, and owing to the distances involved, the pumpability of the grout becomes a major issue. In some cases, the presence of groundwater may change the mechanical properties of the pumped grout. There are several key problems associated with grouting.

The first and most important problem is grout strength, which is usually checked by compressive strength test using cubes (ASTM, 2020), as shown in Fig. 1. Grout strength is a measure of the material's capacity to resist change of size due to tending loads. Strength may be compromised due to the varying environmental requirements of the target location. The variation in strength can be assessed by casting the cubes both underwater and in air and then comparing the strength test results of each.

The second key problem associated with grouting is fluidity and pumpability, which are usually estimated by slump and slump flow (ASTM, 1997), as shown in Fig. 2. Traditionally, a cone is filled with grout or concrete; then, it is lifted up, and the spread of the grout or concrete below is measured. Due to the designed increase in viscosity to counteract wash-out, grouts lose pumpability, meaning that the potential distance of pumping decreases from

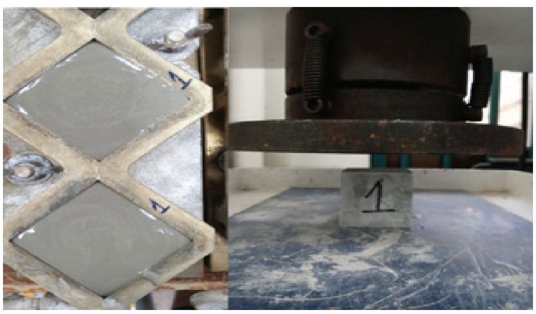

Fig. 1. Compressive strength test and cubes.

Fig. 2. Mini-slump spread for pumpability.

Fig. 3. Water penetration test for permeability. (Maria Eugenia, P. R., 2018).

(a) Dispersive grout (b) Non-dispersive grout

Fig. 4. Anti-dispersity checking in water.

hundreds of meters to only a few meters.

The third key problem concerns durability or permeability, which is usually checked by a water penetration depth test (BSEN, 2019), as shown in Fig. 3. In this test, the resistance against water penetration under hydrostatic pressure is checked and measured. A lower the permeability indicates a better grout mix design, because it does not allow chemicals and water to percolate through the mix. In comparison, high permeability results in the leaching of calcium hydroxide from concrete or grout in the presence of groundwater. The resulting absence of calcium hydroxide creates enlarged pores, causing greater water percolation and results in further degradation of the cement material.

The fourth key problem pertains to anti-dispersity (Khayat, 1995), as shown in Fig. 4. Dispersion results in cement particle scattering in groundwater and the carrying away of the material through cracks and joints.

2. Previous research

Geotechnical engineers regularly face numerous problems when performing underground grouting. Accordingly, to develop anti-washout grouts for underwater construction or for the grouting of karst formations, various researchers have conducted relevant studies. Li et al. (2019) prepared an anti-washout grout mixture with constituents such as Portland cement, water, xanthan gum and water glass. However, because of its high viscosity, the resulting grout mixture is barely pumpable to deep locations and has a very low compressive strength. The results revealed a compressive strength of 3 MPa for 3 days and 5 MPa for 28 days of water curing with a short setting time value of 62 s and an extreme value of 68 s. This demonstrates that the grout under study cannot be used for deep target locations. Using an anti-washout admixture (AWA), Jaff and Hamid (1997) made anti-washout cement grout for use in dam curtains and in tidal zone rip-rap. Using a viscous modifier and coarse aggregate, Kim and Cho (2013) made an anti-washout grout to compare its applicability in the presence of seawater versus fresh water. Heniegal (2015) stated that the reduction in compressive strength ratio (t) due to underwater casting of cubes and different levels of AWAs is very large, as shown in Fig. 5. It was confirmed that higher AWAs content results in lower compressive strength and that optimum level of AWAs for the highest relative compressive strength (compressive strength out of water/underwater compressive strength) is 1% of the cement weight. Excessive doses may cause higher air content and an increase in anti-washout properties and cohesion, which directly affect the workability and pumpability of the cement grout. An important factor affecting the properties of the grout (relative compressive strength and anti-wash out properties) is the cement content (number of kilograms in 1 cubic millimeter), as shown in Fig. 6. According to Heniegal (2015) the cement content requirement for anti-washout properties is 450 kg/m^3 without AWAs and 350 kg/m^3 with AWAs. The relative compressive strength obtained using different levels of cement content and AWAs is shown in Fig. 7. Zhang (2015) studied variations in the content of AWAs, which cannot only produce an increase in anti-dispersity but also a decrease in fluidity and pumpability. He suggested that the content of the AWAs should be limited to levels from 0.1-10% of the cement weight. Naik (1994) stated that the permeability of chloride and water can be reduced by 50%, if cement is replaced by fly ash to almost 50% of the weight in the anti-washout grout or concrete. The addition of fly ash or water-proofing agent can decrease the permeability of anti-washout grouts and concretes. Cui (2017) made two anti-washout grouts using Portland cement, accelerating agents, flocculating agents, cationic polyacrylamide (CPAM), hydroxyethyl cellulose ether (HEC), UWB-II (underwater binder),

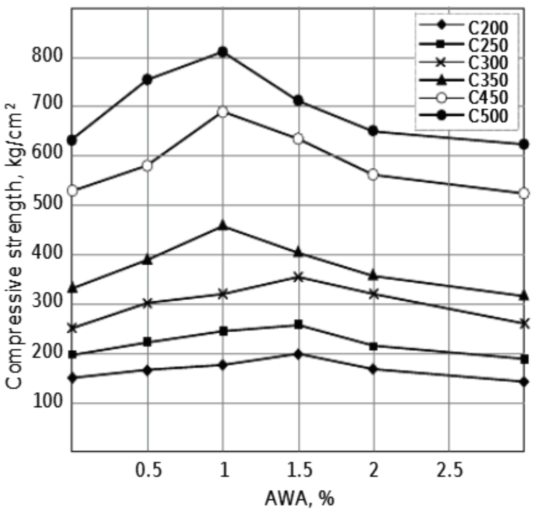

Fig. 5. Effects of AWA on self-compacted concrete (Heniegal, 2012).

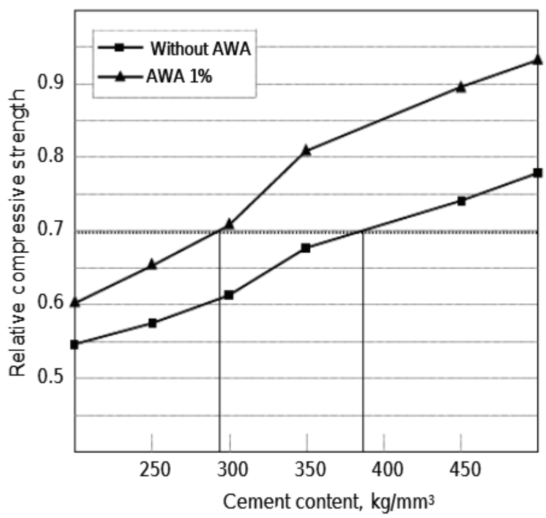

Fig. 6. Effects of cement content on underwater/out of water strength (Heniegal, 2012).

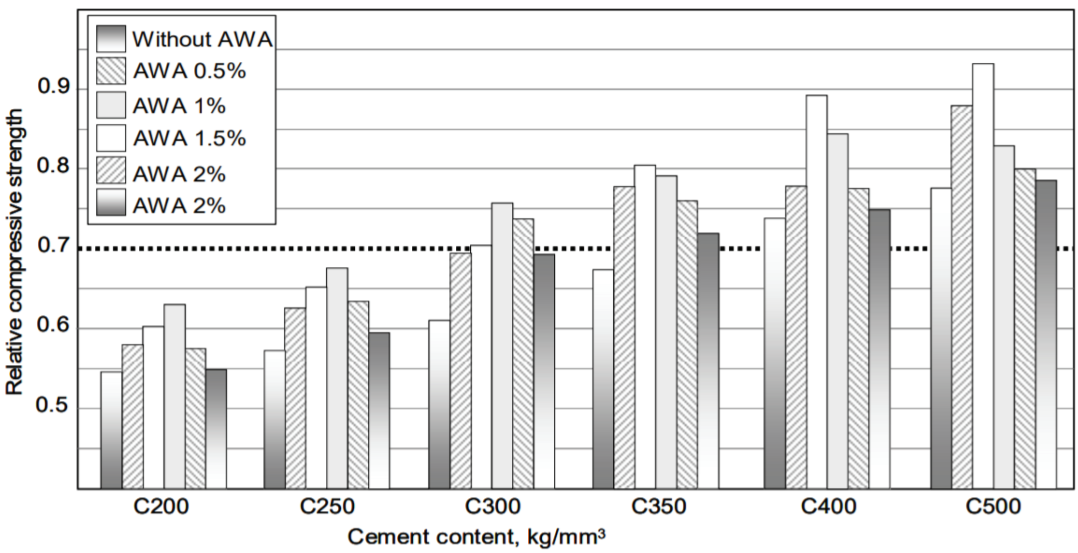

Fig. 7. Relative compressive strength in the presences of different levels of cement content and AWAs (Heniegal, 2012).

Table 1. Materials used in grout and the environment

Authors(year of publication)	Materials used for grout	Usable environments
Jaff and Hamid (1997)	Anti-washout admixture (AWA), Portland cement, water	Grout curtains and grouting of tidal zone rip-rap
Bury (1997)	Portland cement, cellulosic polymer	Near-surface environments
Kim and Cho (2013)	Viscous modifier, coarse aggregate, seawater	Grouting in the presence of seawater
Shucai et al. (2019)	Portland cement, water, xanthan gum and water glass	Near-surface cavity sealing
Cui (2017)	Portland cement, accelerating agents, flocculating agents (CPAM, HEC, UWB-II), and bentonite	Near-surface environments

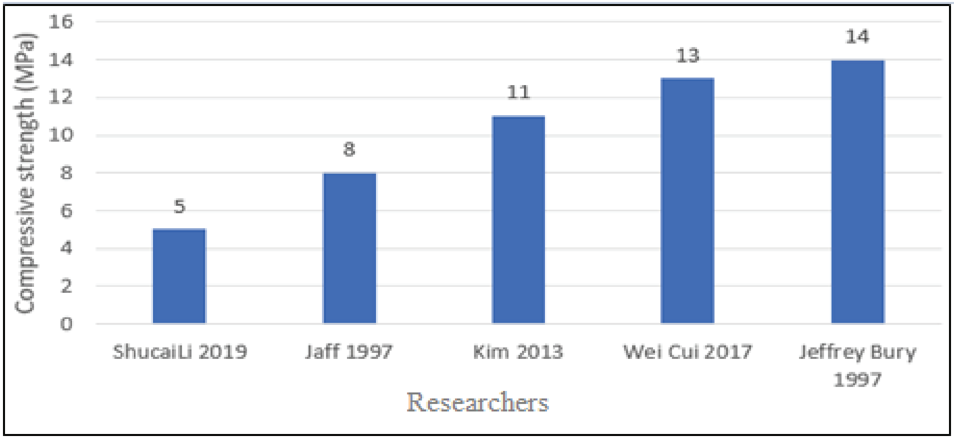

Fig 8. Compressive strength of different anti-washout grouts.

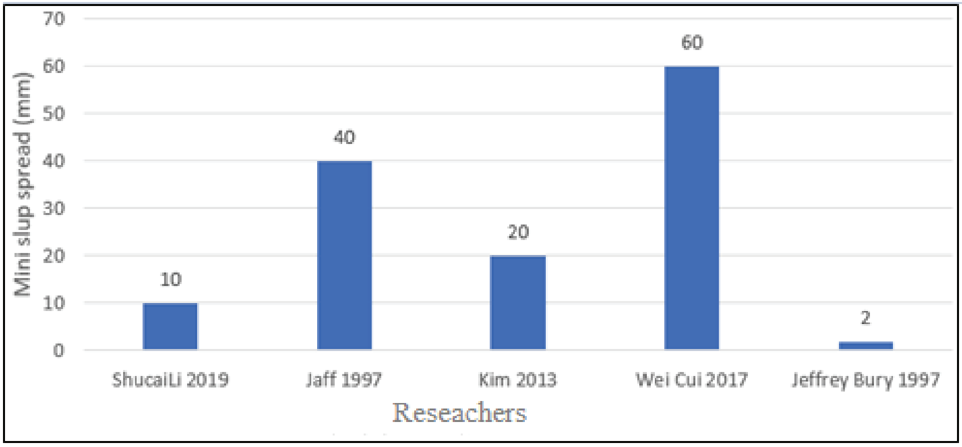

Fig 9. Mini slump spread of different anti-washout grouts.

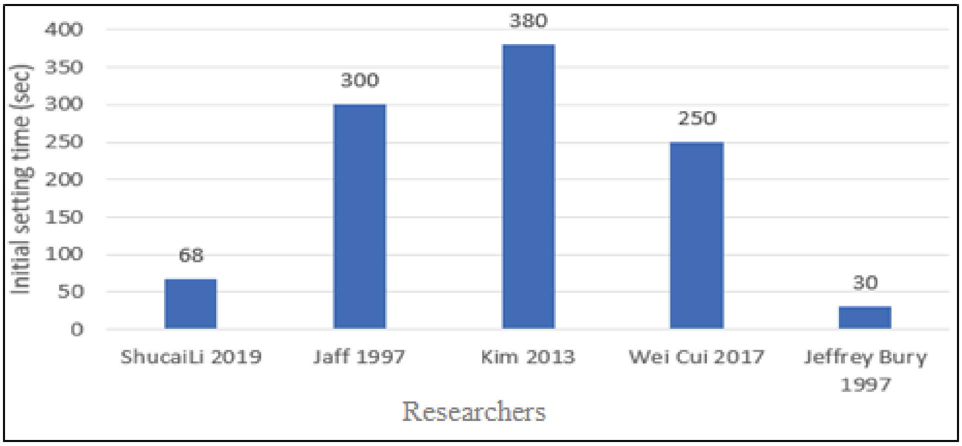

Fig 10. Initial setting time of different anti-washout grouts.

and bentonite. Both grouts had a maximum slump spread of 60 mm, which means that the grouts are not pumpable grouts, and a maximum 28-day compressive strength of 13 MPa. Other types of grout have been developed to control extreme water flow in streams and for the sealing of surface springs. Bury et al. (1997) developed an anti-washout grout using Portland cement and cellulosic polymer that exhibited low fluidity to zero flow, which indicates that this grout can be used only near the surface. There remains a large gap in the field of underwater grouting when the grout is subjected to different target permeabilities the under surface and subsurface conditions.

Two of the most important factors considered by researchers are strength and flowability or mini-slump spread. Grout must be flowable so that it can be pumped to different depths and locations.

3. Conclusions and Discussion

1. Different materials are used by researchers for the anti-washout grouts for the different environments. But there is a relatively little information regarding field application of high viscosity non-dispersible grout in real field conditions and in variable subsurface conditions.
2. Currently most of the researchers are concentrated on laboratory trials to develop suitable grouts and these have been designed and optimized for possible application in various ground conditions to achieve specific objectives. Only limited information is available regarding application of high-viscosity and non-dispersible grouts in real case histories.
3. As stated above, researches have been focused on the strength, fluidity or pumpability, non-dispersity, and durability or permeability of anti-washout grouts, and very few researchers studied about the effect of expansion for anti-washout grouts due to its casting in water under the grouting condition getting enough time to cure.
4. Future researches for such grouts should concentrate on real field applications to assess their suitability for workability, ease of pumping, permeation and the strength gain with time, and so on. Implementation of these grouts must be carried out by developing the target environment permeability and ground water conditions. There is a need to study the bonding strength of the anti-washout grouts in addition to achieving higher strength in the case of non-graded aggregates, graded aggregates and in fissured rocks of variable permeability under various hydraulic gradients.

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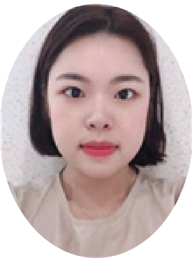

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