Studies of FUL Grout by Experiment

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ABSTRACT

Lignin grouts are cheap and easy to get. They have some desirable properties, but they are less used now because environmental pollution is often caused by Cr^{+6} from the lignochrome component of the grout. Their usefulness was researched in an earlier paper on lignin as a grout from other viewpoints. A non-toxic grout FUL was made composed of furfural, urea and lignin. After initial tests, including tests by spinning regression design, some response equations in which FUL's properties are described were obtained.

Optimum formulations have been established by using optimization methods based on response equations. The engineering quality was assured by formulations whose properties were measured in further tests. The mechanical feature of gelling sand was measured by means of triaxial tests. This provides a basis for using FUL grout in-situ. Finally, an in-situ experiment on FUL was completed successfully. The results were that cracks in stratum were filled or blocked, the gelling of FUL had high strength, and low permeability and consolidation were achieved.

SUMMARY

Grouting has been used for more than 180 years. Chemical grouting has had 100 years' history. However, the application of organic macro-molecule grouting material has been applied for less than 40 years, but its development has been rapid. Grouting has solved many difficult engineering problems, and it provides certainty in achieving engineering results with speed and quality.

The first problem that must be resolved in grout planning is the selection of the grouting material. The proper selection of grouting material is critical to the success or failure of grout engineering. At present, most grout materials are expensive, and research into low cost grout materials with properties to meet the needs of engineering quality is extremely important. Further, most organic macro-molecule grout materials are toxic and polluting in the environment. Thus, the problem of toxicity of grout materials is another important problem.

Past workers did a vast amount of study on grout materials. The authors presented a paper on new grouting material - LigninChrome - Waste in the First International Mine Water Congress IMWA (Budapest 1982). This grout material uses cheap material and produced low Cr^{+6} levels, but toxicity still existed. The Mine Research Institute in Changsian studied Neodymiumlignin in 1984, and overcame the problem of Cr^{+6} toxicity, but it still had problems in that the gel contracts, on set up. Further, it exhibits poor permeability properties and the formaldehyde used to achieve gelling is difficult to handle. The Coal Science Research Institute used a different form of lignin grout, furfural-urea, to consolidate running sands in 1977 and thus experience was gained in this area.

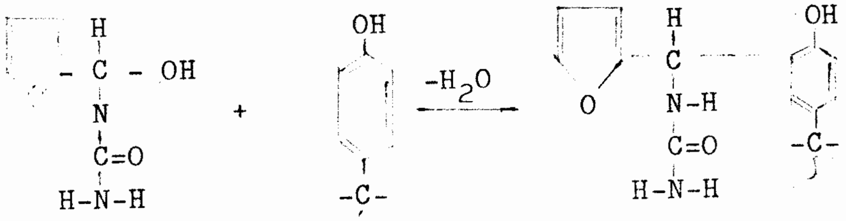
FORMULA STUDY AND LABORATORY TEST

By comprehensively analysing grout materials for their and strong and weak points, the authors sought to develop non-toxic, cheap material which can still meet the needs of engineering in terms of low permeability and strength. The materials incorporated together were furfural, urea and lignin (FUL).

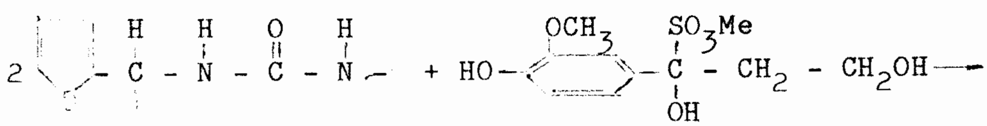
First, they sought to prove the grout FUL lignin in theory:

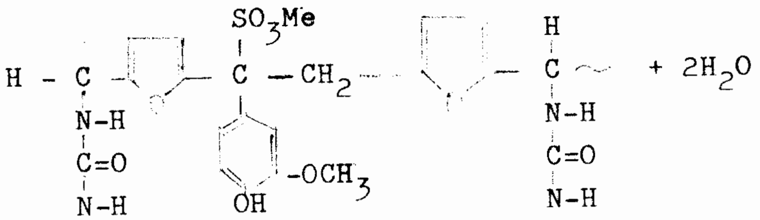
Theoretical Evaluation of F.U.L.

At the beginning of reaction, furfural reacts with urea to form furan methyleurea. Because the hydroxyl and phenolic groups in the lignin have high reactivity, they react with furan methyleurea through condensation to form three dimensional polymers. The lignin molecule with more than two hydroxyl, also acts as the connection agent. Its main reactive formula are as follows:

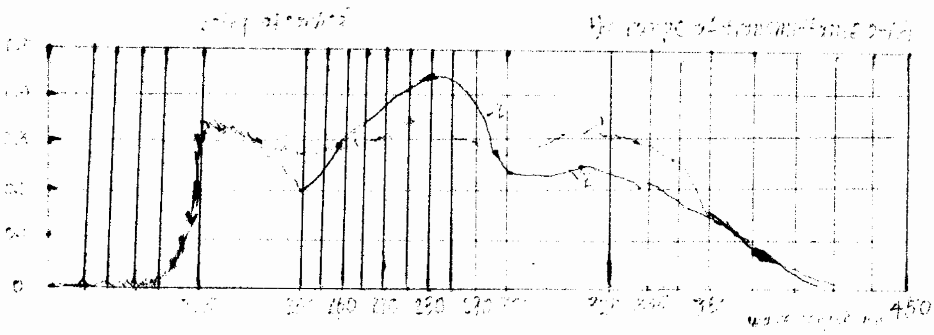


(1)



 (2)

By analysing the products of the above reaction it was discovered that the ultraviolet spectrum coincided with that of lignin (280mm) (Figure 1). This shows that the polymer structure is characteristic of the basic lignin group.



1. The ultraviolet spectrum of furfural urea
2. the ultraviolet spectrum of FUL

Experimental Developments

Initial experiments at generating grouts in the laboratory used lignin from the acid waste water of seed pulping. This was unsuccessful due to the lignin content being too low and the marginal chemical components too high. Pulpwood waste lignin evaporated to dryness however gave satisfactory results. Experimental practice used spinning regression techniques for mathematical analysis and this generated a regression equation that reflects the changing properties of FUL. ie.

$$\hat{Y}_r=-471.42+17.7713Z_1+4.7386Z_2+1012.14Z_3+14.63Z_4 -0.04936Z_2^2-826.85Z_3^2-0.2173Z_4^2-19.48Z_3Z_4 \quad (3)$$

Where Z_1, Z_2, Z_3, represent the quantities of furfural, lignin, and sulphuric acid used, Z_4 represents its temperature. Y_r is the strength of gelling body.

On basis of this formula, the authors developed a further formula to determine the optimum grout formulation required to satisfy economics and the engineering requirements of the job.

This mathematical expression is:

$$\min \frac{10^3}{14+Z_1+Z_3}(2.79+2.784Z_1+0.042Z_2+0.2204Z_3)$$

$$\text{s.t.} \quad \hat{Y}_r \geq A$$

$$\hat{Y}_t = B \qquad (4)$$

$$\hat{Y}_\eta \leq C$$

$$\hat{Y}_k \leq D$$

Where A, B, C, D, are constants determined by specific engineering demand; Y_r, Y_t, Y_n, Y_k are the regression functions of Z_1, Z_2, Z_3 and Z_4 (formula (3)).

Evaluation of FUL Properties

FUL is a low cost non toxic chemical grout material with high strength.

Its major properties are:

(1) The gelling time may be controlled in several ways, but there must always be a proper coordination of sulphuric acid and temperature. Provided the Z_3, Z_4 coincident point falls in the shaded portion of figure 2, the reaction will perform properly.

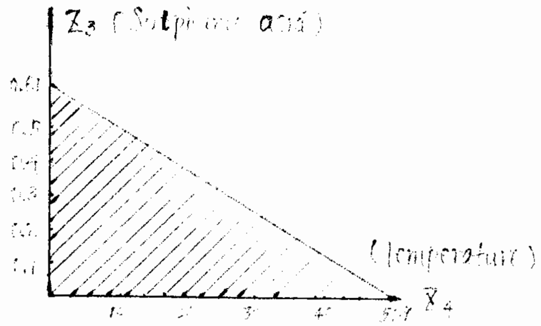


Figure 2. Relation between sulphuric acid quantity and temperature.

(2) Strength may be controlled at will between 0.5 and 13 MPa. Strength (R) changes with time (T number of days) according to the following formula:

(3) The osmotic coefficient of consolidation of the body is small.

(4) The acid and freeze resistance performance of the gelling body are good, but the water retention and water uptake performance gives problems of crack development.

(5) Triaxial cell tests show that cohesion of grout gelled sand bodies is very high and that FUL is a good reinforcing agent.

To improve the flow properties of the grout, Na_2SO_4 solution (1%) may be used.

ENGINEERING EXPERIMENTS

On the basis of above study of the theoretical and laboratory experiments, FUL was used to seal water leaks in the water inlet terminal to the Sanjiazi Power Plant (Figure 3).

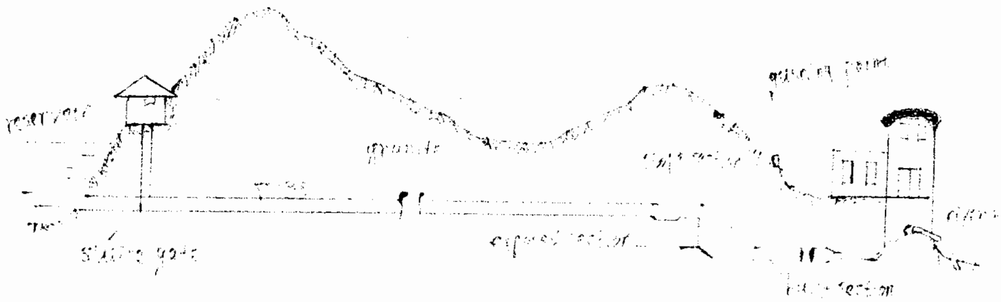


Figure 3. The vertical section sketch map of Sanjiazi Power Plant Drawing Water Drift, Ji Lin.

After the power plant was brought into service water, leakage from the tunnel created potentially hazardous geotechnical conditions in the rock wall behind the power station. Flows in summer in excess of 7m^3/hr were measured. It was decided to seal the inside of the tunnel with silica gel and to inject FUL grout into the rock to seal the fractures which were discharging water from the rock wall. In the rock near the water eruption point on the mountain slope, ten grouting holes were drilled, and 906 litres of FUL grout liquid were injected. Five months after the experimental grouting with FUL, cores were collected to observe the grout effect. It was found that all the cracks were filled with FUL grout. All the water leaks were blocked and the slope had been reinfored by the grouting. The landslip hazard has been removed.

Figure 4. The "Ice Wall" formed from leaking water in winter.

More practical experience is necessary with this grout, but this is expected to occur in the coming years and the process will be perfected.

CONCLUSION

The research results show that, as an organic macromolecular chemical grout material FUL has many advantages in reducing permeability and in consolidating rock strata. FUL is considered to have a good future. Its chief performance parameters are listed in table 1. FUL is an inexpensive, non-toxic and high strength chemical grout material.

Table 1 The Performance Parameters of FUL Grouting Material

Formula	Performance	
Sulphuric acid 0.5-3%	Gelling time	tens seconds several hours
	Compressive strength (MPa)	0.5 - 13
	Viscosity (CP)	12 - 40
	Acidity (PH)	1.6 - 4.5
Urea lignin 64-87%	Specific Gravity	1.183 - 1.226
	Permeation coefficient (cm/sec)	3.48×10^{-6}
	Cohesive force (MPa)	1.35
	Toxicity	non-toxic
Furfural 13-36%	Durability	good
	Making Price(yuan/T)	539 - 1000

REFERENCES

* Du Jiahong, "Application of New Lignin Grouts in Sealing of Soils", pp. 259-277, Proceedings on First International Mine Water Congress of IMWA Budapest (1982).