Inflow Prevention
GENERAL REPORT

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ABSTRACT

This report reviews four papers covering different aspects of mine water grouting. The papers are by:

Zabora V.V. Senior Mining Engineer of Spetstamponazgeologia (S.T.G.) from Russia who titles his paper:

"Exclusion of Residual Water Manifestations in Mine Workings";

Zhou Xingwang and Liu Shuqing of the Central Coal Mining Research from Beijing in China titled:

"Testing Rig for Fracture Grouting";

Wang Guoming, Yang Chunlai and Wang Yinxiang, the first two authors being also from the Central Coal Mining Research in Beijing, with the last authors being from the Shang Shuping Colliery of Shanxi Province in China entitled:

"Grouting Technology for Control of ordivician Limestone Water in Malam Colliery";

and finally

Du Jiahong and Juang Pinghui who are respectively Professor of Mining Engineering at the Northeast University of Technology, Shenyang in China, and Engineer Construction Research Institute in Fuzhou in China.

These four papers cover a broad spectrum of grouting technology including chemical, cementitious and stabilized clay grouts; the theory of grout curtain and programme design and discussion of practical results.

ZABORA, V.V.

Mr. Zabora discusses what he considers to be a proper basis for design of past grouting progammes around mine workings. The environment is one in which water problems derive from breakage of the rock mass as a result of both primitive stress and stresses which generate around mine openings.

Mr. Zabora identifies "zones of technological influence" in which the properties with respect to water inflows can be described by an average value which is different from those of the rest of the rock mass. He further defines the "disturbed rock zone" (DRZ) which closely surrounds the mine opening.

He comments that the conventional approach of cover drilling has many inadequacies, these include unpredictability, loss of development production time, but most importantly the shallow depth of grout holes precludes the use of high pressures in grouting and as a result often only achieves a redistribution of water inflow zones. These comments are very interesting and should be considered against the case history approach presented by Wang Guoming et al.

In theory, Zabora states, there are three characteristic zones around mine openings, namely:

- zone of ruin failure where the rocks may be transformed more or less to a loose mass;
- zone of post failure in which failure occurs because of the mine opening, but along predetermined failure axes, and
- zone of prefailure where the rock is unchanged by the stresses associated with the development or existence of the mine opening.

The first two zones involve non elastic failure and they have a geometry which can be calculated. Continued failure will occur in these zones even after a lining or support has been placed. This can only be offset by introducing binding material so that the stress field develops more uniformly with less concentration on the mine opening.

Mr. Zabora makes the point that grouting to reorient and reduce stress concentrations is not effectively achieved in the disturbed rock zone which extend out to the margins of the zone of post failure because even after the placement of liners, non elastic failure will continue within the D.R.Z., thus grouting in this zone may fail.

These problems may be avoided if the pattern and depth of grout holes is designed taking account of the stress concentration radii around the workings and the rheological and mechanical parameters of the injected grout.

He then proceeds with a calculated example of a project undertaken by S.T.G. In the design of the operation the necessary thickness of the grout curtain and the angle of drilling necessary to place that thickness outside the D.R.Z. is calculated and the length of the holes is predetermined.

The drilling and injection sequence is decided on the basis of the uniformity or otherwise of the fracture porosity and permeability in the prefailure zone. The volumes of grout must be sufficient to both create the curtain thickness determined to be necessary and to achieve interlocking between the grout placed from each hole. The latter is a function not only of the formation parameters but also of the rheological properties of the grout and the pressures which can be applied, without causing failure in the workings or undesired hydrofracturing of the rock mass (unpredicted failure).

Mr. Zabora comments that the use of stabilized clay grouts will generally be an optimum engineering solution. With this approach the mixing plant can be placed at the surface removing the problems of pressure, and disturbance of underground operations, and the greater thickness plus the long term plasticity of the material not only ensures high sealing effect but also contributes to a more uniform stress field generation.

WANG GUOMING et al

Wang Guoming and his fellow authors describe the techniques they have used to overcome mine water inrush problems from faulted fractured and karst limestones in a coal mine.

Problems with water were encountered in several shafts and in the main incline over considerable lengths (30-100 m). The problems were identified in advance of development by probe drilling and had to be resolved rapidly so that the mine could be brought into production.

The approach selected included sectionalizing the water inflow zones on the basis of convenient length (20-30 m) or hole discharge (10-20 m^3/hn). The grout holes were drilled at an angle such as to place the grout curtain 3-4 m back from the edge of the proposed workings and in an ellipse around the working. Nineteen grout holes were drilled in one section. Grout was injected first into holes which showed the highest flow. Thereafter grouting was injected in sequence into the floor holes, matched pairs of side holes, with the roof holes last.

Grouting and drilling were progressed simultaneously in order to reduce the inflows the mine had to handle and to check the effect of the grouting.

The grouts used were cement water slurries varied in the ratio 1:0.6 to 1:3. Thick grout was injected initially except where fractures were thin or in later stages. The grouting pressure was designed at 2-2.5 mPa which was 3-4 times hydrostatic head, but was increased to 5-7 mPa dependant upon operational conditions.

The authors comment specifically on the care needed to create the grout pad and to stabilize it and the pressure standpipes on the holes.

Their efforts were successful.

The paper is a very interesting counterpoint to that of Zabora. Clearly the authors had substantial knowledge of the geometry of the major water bearing structures, but it is not clear what if any geotechnical evaluations of the stress fields were undertaken or whether non plastic deformation of the rock mass around the working was a factor in inflow exacerbation.

It is not clear what geological basis there was for the sectionalization of the incline grouting nor is there any comment of the linings or support being applied in the workings.

Finally the grout mixes used and the pressures applied seem likely to have suffered considerable bleeding (synenesis)and may not have been effective in achieving full fissure permeation. Also the potential for hydrofracturing may have been high at the higher grouting pressures.

At no time do the authors comment upon the basis on which grout injection was continued or terminated, or the basis on which grout mixtures were varied.

They comment that 1200 tons of cement was placed around 307 m of opening. If a rock void space of 5% is assumed, this represents a radial grout curtain thickness of 8 m. Considering cement grout strengths on set up this would appear to be excessive where the hydrostatic heads were only about 64 m. However the operation was almost certainly justified by the rapidity with which they achieved successful grouting. Certainly had pregrouting not been practiced, delays in recovering from the inevitable water inrushes would have been much worse, and may not have been achievable.

ZHOU XINGWANG and LIU SHUQING

This paper discussed a laboratory test rig for assessing the efficiency of grout permeation into fracture zones under pressure and the permeability of the grouted fracture after set up. It has the capacity to permit simulated grouting trials with any sort of grout and with varying fracture widths at pressures up to 16 MPa.

On completion the grouted fracture can be cored for inspection and the cores subjected to standard geotechnical tests.

The authors present a set of test results from experiments carried out to define pressure grouting of a nature similar to that described at the Malam Colliery by Wang Guoming et al. Two case histories are presented. In the first, two cement grout slurries were tested against two static pressure levels and for three fissure openings. Pressure time curves, antifiltration capacity, dispersed distance and stress strength results are presented and their application is discussed with the results achieved in actual grouting presented.

The second case history refers to grouting of sand, gravel and sandstone layers. It is not clear from the paper, but presumably the intermittant grout injection technique employed was piloted using the test rig described.

The authors conclude that the laboratory grout testing rig is a useful tool and that it has allowed the classification of the characteristics of pressure/time curves for water/cement slurries to be defined. Further, they have observed that the antifiltration capacity and mechanical strength of grouts do not always decrease down the axis of dispersion.

The paper is a valuable contribution in that it provides a tool for grout experimentation. Its only limitation is the range of inground conditions which can apply and its lack of capacity to assess the interactions which can occur between those phenomenon such as varying fracture opening, water loss from grouts to permeable formations and the impact of hydrofracturing.

Taking these aspects into account the Rapporteur is of the opinion that the test rig is a valuable new laboratory testing facility which could be very valuably employed in producing some standard curves for a wide range of grout mixes in a wide range of grouting environments. In this way table of grout properties could be generated which would expedite the selection of grout formulations to suit particular environments and give confidence to mining engineers confronting grouting operations that the properties of the grout are fully understood.

DU JIAHHONG and JUANG PINGHI

The above authors describe the continuing process of research which has been undertaken to develop a new, environmentally safe and effective chemical grout to replace the now discredited chrome lignin grouts. The grout discussed is a furfural urea lignin grout (FUL), which is a polymer generated from the reacton of furfural, urea and waste wood pulp lignin.

Spinning regression analyses have been used to analyse the component concentrations which are necessary to generate a variety of engineering properties including setting time, gel strength and chemical attack resistance. Other chemicals which can be added to catalyze the polymer generation and/or to improve flow properties are described.

The authors go on to describe its application in sealing and stabilizing a fractured granite mass suffering degradation due to a leaking pressure tunnel between a dam and hydroelectric power generation station. The tunnel lining was sealed with a silica gel grout and the rock mass with FUL grout successfully.

The authors recognize that crack development due to shrinkage on gelling up is still a problem, but that the grout is inexpensive, effective and delivers only marginal chromium toxicity. Further development is expected to resolve these problems.

RAPPORTEUR SUMMARY

The four papers are all valuable contributions to grouting technology in that they explore the extent of modern grouting technology. Most grout applications in mining are entered into reluctantly by mine managers under constraints of time and with severe economic pressures and demand for performance. All too frequently the problems have not been identified in advance.

These papers advance grouting engineering by proffering experience, advice, techniques and methodology. More than this, they should generate an awareness and a confidence that grouting does not have to be the uncertain practice which many mining engineers have experienced in the past.