Surface Grouting of Circular Roadways

* By J. MARTIN, BSc(Hons)

INTRODUCTION

When it is required to place large quantities of grout below ground several advantages may be obtained by positioning the grout mixing equipment on the surface and conveying the mixed grout to the point of use by pipeline. These may be summarised as:

(i) No shaft time is used for the transport of bulk materials.

(ii) Emphasis below ground can be put on the correct placing of the grout, rather than the problems associated with its mixing and pumping.

At Shirebrook Colliery approximately 2000 m^3 of 30 MPa strength cementitious grout was used to backfill the annulus of 1000 m of 5.4 m diameter circular arched roadway within the Deep Soft Seam. This is equivalent to approximately 3500 t of bulk material, which would have required the transport of 1166 three tonne mine cars underground. The requirement in filling the annulus of the roadway was to reduce the possibility of point loading and resultant distortion of the circular arch. This has proved successful over the first two years and these roadways should have a long life without the need for any backripping or dinting operations.

In October 1988 Cementation Mining Limited (CML) was awarded the U26 development contract at Warsop Colliery. Part of this contract involved the establishment of a surface grout station to pump a 4 MPa grout mix over a distance of 3000 m to backfill the annulus of the circular roadways.

From experience of grouting from the surface the author now considers it to be an area where British Coal could make significant financial savings in the future.

1. THEORETICAL REQUIREMENTS

When it is intended to pump grout from the surface into a mine there are a number of interacting factors which must be taken into account:

(i) Grout fluidity.
(ii) Grout density.
(iii) Grout pumping life.
(iv) End use of grout.
(v) Placing rate.
(vi) Vertical drop.
(vii) Horizontal distance.
(viii) Overall pipeline length.
(ix) Pipeline diameter.
(x) Pipeline roughness.
(xi) Pipeline bends.

Consider the system shown in **Fig. 1.**

The major factors are considered in detail below:

1.1 Pump House Pressure and Flow Rates must be Realistic

The pump house pressure and flow rate are directly related to the static head and the pressure loss along the pipeline. The static head can be calculated from the difference in datum levels between each end of the pipeline. The pressure loss along the pipeline is more difficult to calculate and is dependent upon the fluidity of the grout, the pipeline diameter and the pipeline roughness. There are various theoretical analyses which can be carried out, but more realistic results can often be obtained by conducting surface pumping trials and developing an empirical relationship. Normally, pumping pressures of up to 7 MPa and flow rates of around (1×10^{-3}) m^3s^{-1} have been found to be realistic.

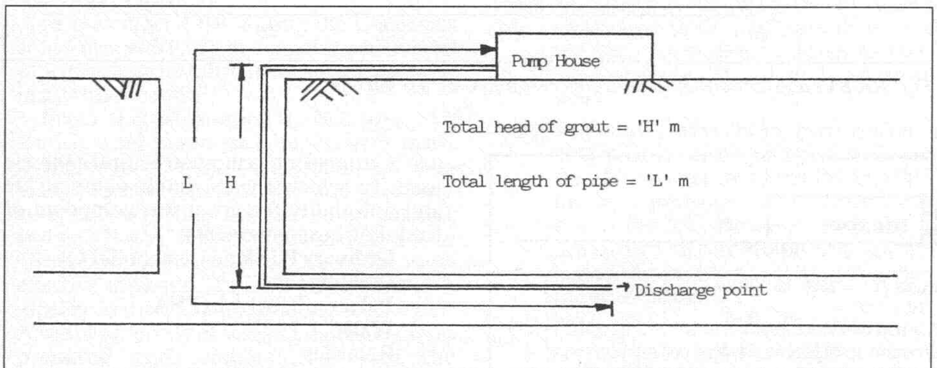

Fig. 1

1.2 The Grout must be Delivered in the Correct Formulation

If the pressure in the pipeline falls below the vapour pressure of water, approximately 2.34 kPa, then cavitation will occur. In this situation the grout will fall under gravity through the empty pipe and segregation of the components may occur. Therefore to ensure the grout is delivered as a uniform mix it is best never to let the pressure in the pipeline fall below atmospheric.

1.3 The System must not Create Blockages

There are two basic flow regimes possible in a pipeline, laminar and turbulent.

In laminar flow conditions there exists a thin stationary layer along the pipe wall and frictional losses are proportional to the velocity. This may cause a build-up with time when using grout mixes unless the pipelines are cleaned regularly. As the flow rate increases the flow regime passes through a transition zone and into turbulent conditions where frictional losses become proportional to the velocity squared. There is no stationary layer along the pipe wall in the turbulent flow condition. Therefore, to reduce the possibility of settlement occurring in the horizontal sections of pipeline the flow should be kept in the turbulent regime (see **Fig. 2**).

Without going into complex fluid mechanics formulae there is a relationship derived from the Froude number of flow for a system of mixed particle sizes:

$$V_{min} = Fr \sqrt{2gD(S_s - 1)}$$

where V_{min} = minimum velocity to prevent settlement (ms^{-1})
g = acceleration due to gravity (ms^{-2})
D = internal pipe diameter (m)
Fr = Froude number (ratio)
S_s = specific gravity of the solids ($kg\,m^{-3}$)

For cement based grouts, with a factor of safety of 1.5, the table shown in **Fig. 3** can be produced. It can be seen that the required flow rate to prevent settlement occurring can be quite high, depending on the pipe diameter chosen.

2. PRACTICAL EXPERIENCES AT SHIREBROOK COLLIERY

The system at Shirebrook Colliery is as shown in **Fig. 4.**

* Mr Martin is a Project Manager, Cementation Mining Ltd

Presented at the 1989 Junior Sections' Annual Meeting held on 16 May 1989 at the Cairn Hotel, Harrogate

MS received by IMinE 21.4.89

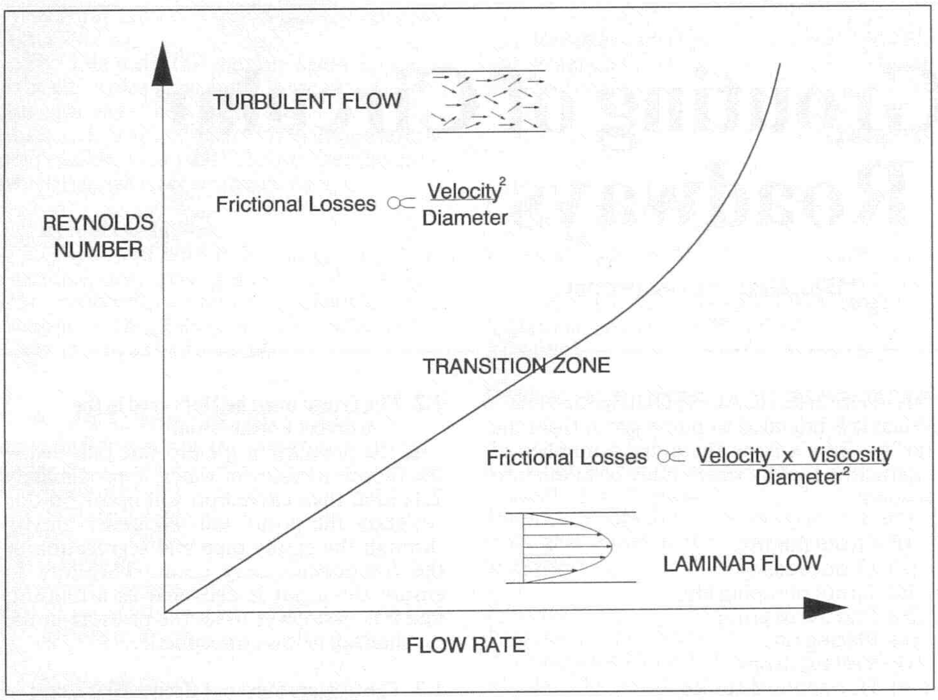

Fig. 2 Turbulent and laminar flow

Pipeline diameter (m)	Recommended minimum flow rate to prevent settlement in the pipelines (m^3s^{-1})
0.025	0.0011
0.038	0.0031
0.051	0.0064

Fig. 3 Table showing recommended minimum flow rates to prevent settlement in various diameters of pipeline.

2.1 System Design

It can be seen from **Fig. 3** that a pipeline diameter of 0.025 m would be required to prevent settlement in the horizontal sections for a cement based grout flowing at around (1×10^{-3}) m^3s^{-1}. However, to comply with the high grout strength specified a dense mix with a high cement content and low water: cement ratio had to be used. Pumping tests with this grout indicated a high pressure loss per unit length along a 0.025 m diameter pipeline at the required flow rate. Unfortunately this meant that the pump house pressures would have been excessive, even with the assistance of the shaft head. Therefore a compromise 0.038 m diameter pipeline was used. This enabled the pumping pressures to be reduced but the resultant flow rate was insufficient to prevent settlement. To overcome this problem a 'ferret' (wiper plug) was sent through the line every day after grouting to remove any build-up of settled grout.

Cavitation was not a problem at Shirebrook due to the type of grout and methods employed. Pump house pressures in the order of 4 to 8 MPa were normally recorded. In order to reduce frictional losses large radius bends and socket joints were used. The socket joints were designed to enable the ends of each pipe length to butt tightly together to reduce the possibility of a ferret becoming lodged at a joint. Union couplings were installed at specific points to enable the pipeline to be split if any problems arose.

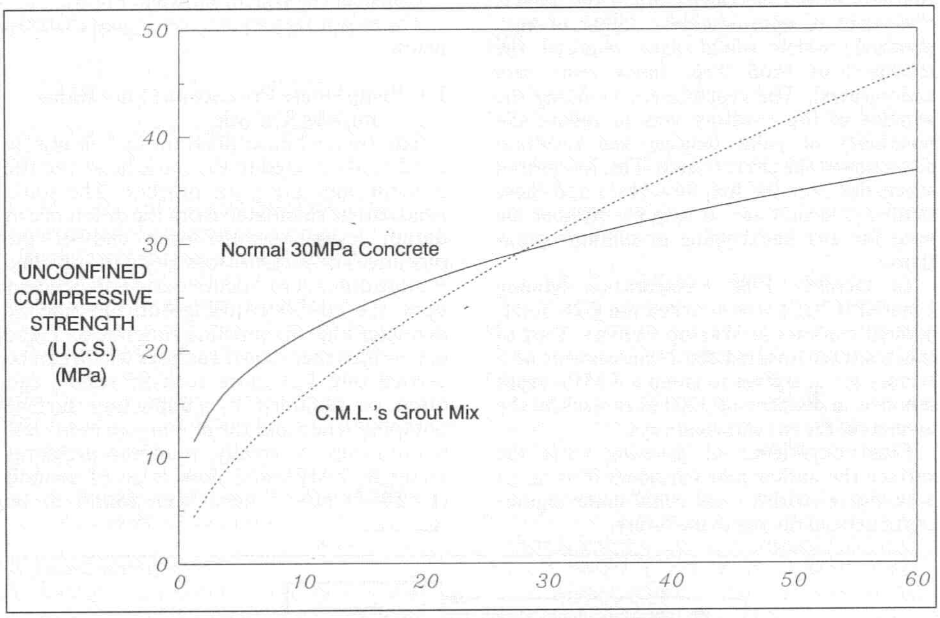

Fig. 5 UCS vs age for normal 30 MPa concrete and CML's grout mix

2.2 Mix Design

As has already been stated the 30 MPa mix used is extremely strong for a fluid grout and is equivalent to most structural concrete used. To achieve the maximum pumping life and flowability the grout was composed of the following components:

- Ordinary Portland Cement (OPC)
- Building sand
- Pulverised fuel ash (PFA)
- Water
- Retarder
- Super plasticiser

Due to the substantial PFA content strengths in excess of 50 MPa are being reached after one year (see **Fig. 5**).

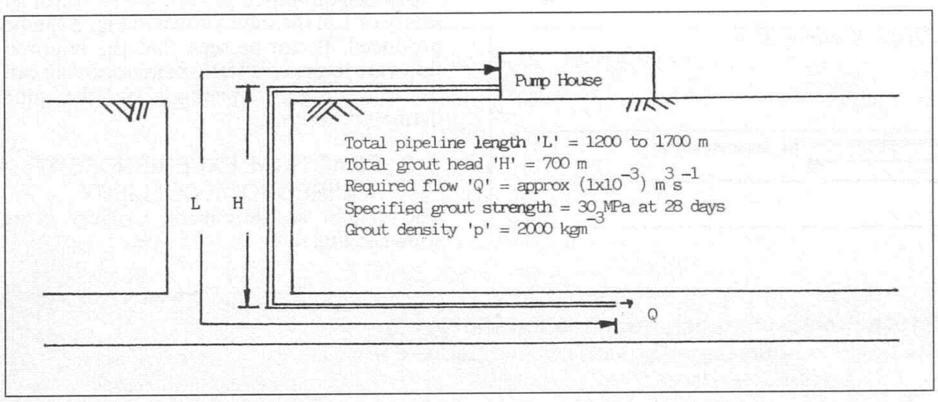

Fig. 4 Shirebrook Colliery system

3. PRACTICAL EXPERIENCES AT WARSOP COLLIERY

In October 1988 CML was awarded the U26