Laboratory Investigations on Grouting of Polyurethane Resins

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ABSTRACT

Results of laboratory study on grouting of polyurethane resin are described. Two types of laboratory equipment are shown - one for study on grouting of fissured rocks, second for study on grouting of rocks with structural porosity. The results of first stage measurements regarding relationship between starting and injecting pressure and stress in fissured rock sample are described. The second stage of tests deals with laboratory process of grouting in pressure box and subsequent testing for the properties of grouted sand and gravel samples, and comparison of the laboratory and in-situ samples of the same materials.

1.0 INTRODUCTION

Significant increase of synthetic resins application in rock reinforcement and sealing in mining and civil engineering requires better know-how of grouting procedures and resulting engineering properties of the final products, i.e., injected rocks.

The programme of laboratory study on grouting of polyurethane resins was carried out in the Institute of Geonics in Ostrava. In the first stage of research programme, following two different materials were identified for study :

* Study on grouting of rocks with structural porosity (e.g. porous soils and low cohesive rocks)

* Study on grouting of fissured rocks (e.g. hard rocks with prominent discontinuities to the structural porosity).

In both cases the properties of rock material are essential for investigation:

* petrography of rock, sort of pores and pore distribution, physical and mechanical properties
* properties of discontinuities (especially width, geometry, filling material, communication).

Knowledge of grout properties is also necessary, which essentially include density, viscosity and their changes with time during polymerisation process. In addition to this , interaction of grouting material with water is also important for such study.

Injection procedure depends on various factors such as grouting pressure, geometry of grouting hole with respect to rock structure and timing and velocity of grouting. The important part of the investigation was to study the structural, physical and mechanical properties of grouted rock and comparison of samples, obtained in-situ with laboratory specimens.

2.0 TEST SET-UP AND PROCEDURE

Test equipment for laboratory study has been developed with an objective to imitate real conditions of grouting procedure.The equipment for testing of grout propagation in rock discontinuities consists of pump, pressure cylinder and grouting jack with sealing, which serves to convey grouting liquid into rock sample under uniaxial loading. (see scheme on Fig. 1). Drilling core with minimum diameter about 80 mm is available as a rock sample. Study can be conducted on brittle fractures and natural or artificial discontinuities roughly perpendicular to the axis of sample. The injection borehole of diameter 10 mm must be drilled in central part of sample to cut the discontinuity. Propagation of grout through fissure on the surface of sample can be observed by special gauges.

The equipment for laboratory research on grouting of porous rock materials consists of two- components pump, pressure box (may be taken into pieces) and injection main from pump into rock sample. The main is provided alternatively at two places - at the bottom of the pressure box or as a perforated tube in axis of the pressure box. (see scheme on Fig. 2).

Two series of investigations using two-component polyurethane resin Bevedol - Bevedan (product of Carbotech Germany) were realised as the first part of the extensive research programme.

The first stage deals with propagation of grout through brittle fractures in carboniferous rocks in the dependence on the stress in rock sample. The research was executed on the two types of carboniferous rocks - siltstones and medium-grained sandstones. The core sample of diameter 100 mm with fracture approximately perpendicular to the sample axis was loaded in uniaxial press and synchronously injected from central hole of diameter 10 mm. Two types of grout with dynamic viscosity 100 and 500 mPa.s were used. Figures 3, 4 and 6 bring main results of measurements with grout of viscosity 100 mPa.s, Fig. 5 shows the results of experiments with grout of viscosity 500 mPa.s. The pressure by which this grout reaches to the surface of sample (all around perimeter) is termed here as starting pressure and injecting pressure means the pressure at which the flow of grout goes into the entire surfaces of discontinuity.

The main knowledge can be briefly expressed :

* the value of starting pressure in comparable conditions is significantly lower than the value of injecting pressure.
* the value of starting and injecting pressure and velocity of flow through fracture are influenced by grain-size of rock.
* the grout propagation has two phases : first is (so called) channel flow, including regularly 20 - 30 % of the discontinuity surface (answers the starting pressure), then the radial flow on the whole surface of fissure.
* the values of injecting pressure and velocity of flow are extremely influenced by the viscosity of grout.
* dependence of starting pressure on the stress at discontinuity is more or less linear.

The second stage study was aimed at grouting of porous rock material and determination of the properties of injected rock samples. In the first series, gravel and sand samples from underground collectors provided at the centre of Prague were investigated. The samples were grouted in the pressure box using polyurethane resin Bevedol NK - Bevedan.

As commonly known, the samples of grouted rock, prepared in laboratory by simple suffusing or mixing are quite different from in-situ samples of the same rock and grout material. The aim of this study was to compare the properties of samples prepared in the laboratory with that of in-situ samples obtained from drived collector.

3.0 OBSERVATIONS

The grouting process in pressure box in laboratory took 3 minutes (amount of grout about 6 litres) and maximum injecting pressure reached 1.5 MPa. The properties of samples from grouted rock in laboratory 24 hours after grouting are shown in Table 1.

Table 1. Physical and Mechanical Properties of Samples from Grouted Rock in Laboratory (24 hours after Grouting)

Sample No.	Density (Kg/m^3)	Elastic wave velocity (Km/s)	Compressive strength (MPa)	Modulus of elasticity (MPa)
1	1330	1.23	3.7	140
2	1410	1.38	8.4	585
3	1300	1.42	1.5	16
4	1410	1.63	6.7	480

Considerable differences between particular samples are caused by different texture of sample, which depends on the distance of sample from the injection point (particularly at the bottom of pressure box). It was observed that the zone structure in the laboratory samples was identical to the zone structure found in-situ. The following zone division from the injection point to the surface of the sample was noticed :

At the distance of 5 cm (from injection point), gravel and sand grains were found to have covered partly by foramy polyurethane with numerous open pores (sample No.1). Approximate volume composition is:

gravel and sand	45 %
polyurethane	25 %
pores in polyurethane	30 %

The next zone at the distance of 17 cm from injection point was created mostly from polyurethane foam without sand grains (sample No 3.) with following composition :

polyurethane	60 %
pores	40 %

Pores were mostly covered.

The next zone (distance from injection point 17 to 35 cm) may be divided into two more or less same thick parts with gradual passage. The zone was created by sand and gravel stuck by polyurethane. The first part (far off surface of the sample) was found more compact, without open pores (sample No 2). Approximate composition :

sand and gravel	45 %
polyurethane	35 %
pores in resin	20 %

The second part (nearby sample surface) was found with more open pores and little crevices with lower content of polyurethane (sample No 4). Approx. composition :

sand and gravel	40 %
polyurethane	30 %
pores	30 %

As a comparison, properties from in-situ samples of injected rock from drived collector in Prague are shown in Table 2. The samples were obtained from reinforced parts beside injection drill-holes.

Table 2. Physical and Mechanical Properties from In-Situ samples of injected Rock from drived collector in Prague

Sample No.	Density (Kg/m^3)	Elastic wave velocity (Km/s)	Compressive strength (MPa)	Modulus of elasticity (MPa)
1	1501.1	0.89	11	800
2	1098.4	2.95	8	600
3	1429.2	1.02	7	700

Fig. 7 shows typical examples of uniaxial compressive strength tests of grouted porous rocks. Sample A is sample 2, sample B is sample 1 from Table 1.

4.0 CONCLUSIONS :

On the basis of laboratory studies carried out on polyurethane resins, following conclusion may be drawn :

* physical and mechanical properties as well as the texture of laboratory prepared injected rocks are very close to the properties of in - situ samples from grouted parts.

* An important feature of injected porous rock is that it has a large deformability, especially behind the compressive strength limit. This property is quite different from original quality of rock and thus may be of great importance for stability of grouted rock mass.

* good cohesion of polyurethane resin with surface of rock grains is confirmed by the fact that in strength test, fissures occur across the polyurethane layers and not along the surface of rock.

* compressive and tensile strength of rocks grouted by foam depends on the mechanical properties of the resin foam.

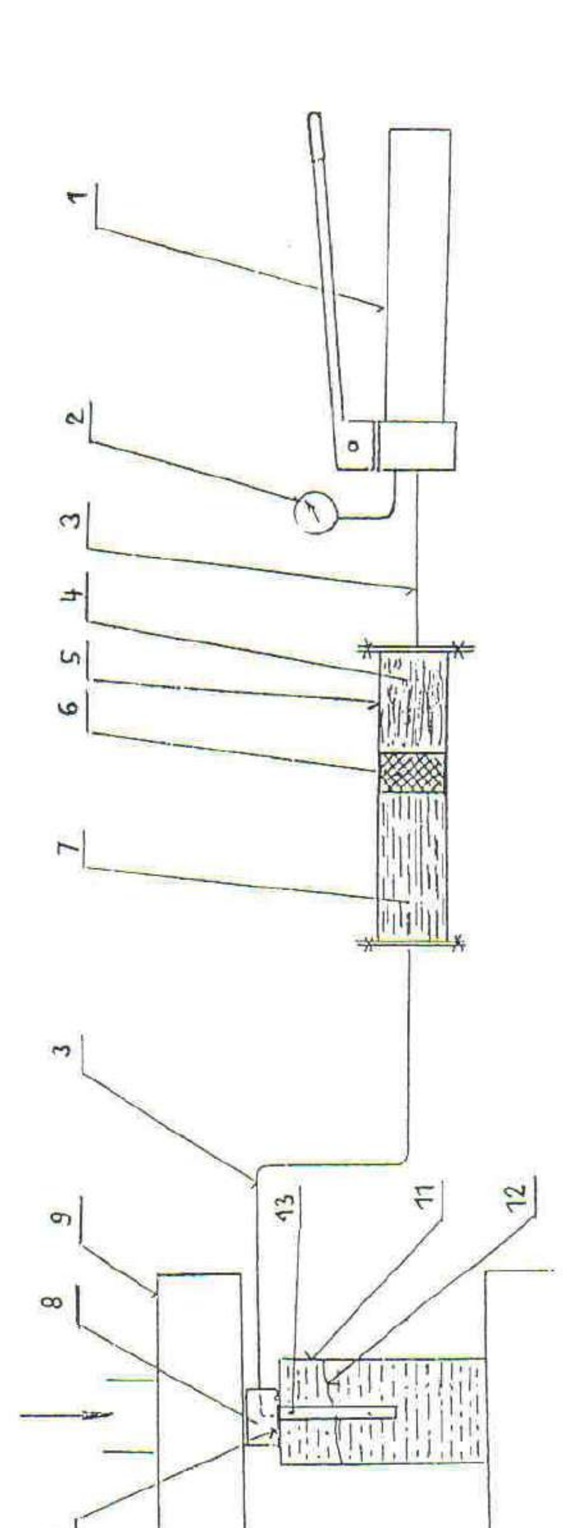
* it is necessary to develop methods of evaluation of texture for intact and broken grouted rock because recent petrographical methods are not sufficient.

The study of grouting process and properties of injected rocks and soils bring worthwhile knowledge from both theoretical and practical viewpoint and it's continuation is requisite.

5.0 REFERENCES

Aldorf J., Vymazal J. (1996) : Prispevek ke studiu pevnostnich a pretvarnych vlastnosti pisku, zpevnenych injektaznimi hmotami na bazi polyuretanovych a akrylatovych pryskyric. Proc.Conf. Aplikace PUR v hornictvi a podzemnim stavitelstvi VSB TU Ostrava.

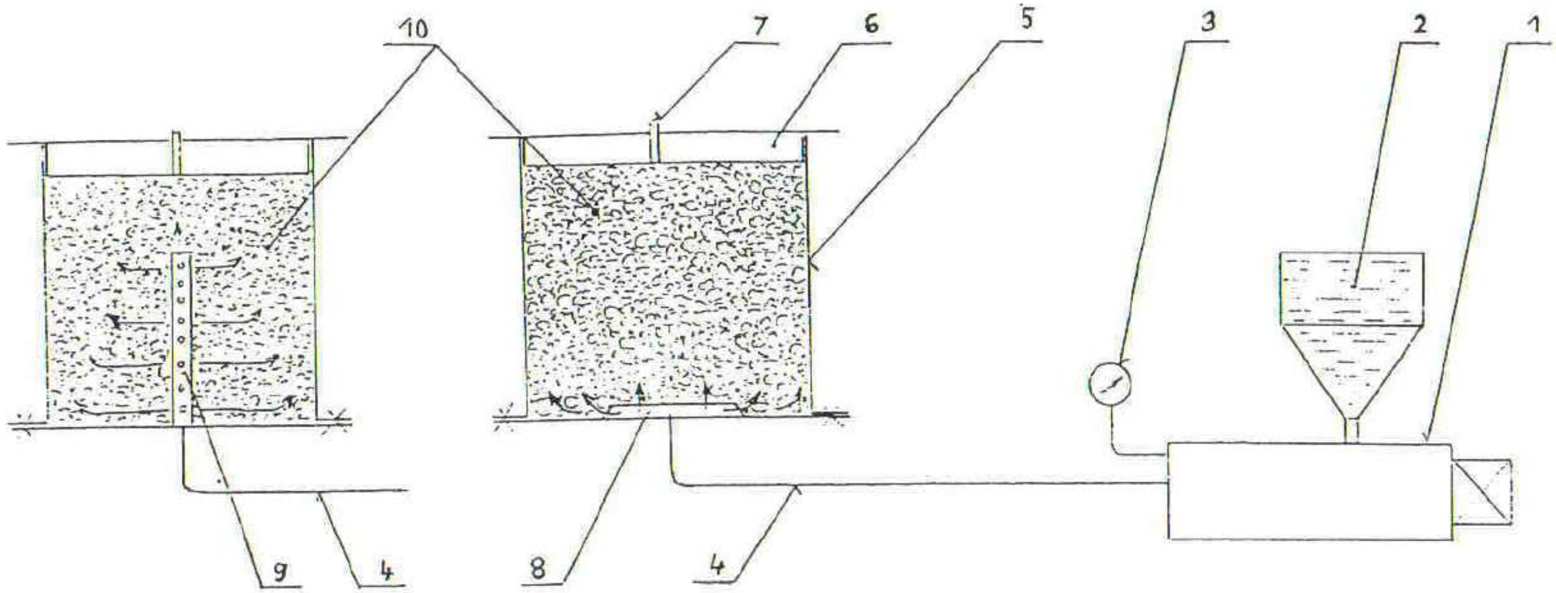
Feder G. (1994) : The pressure necessary to start the grouting procedure. Proc. Conf. Grouting in Rock and Concrete, Salzburg.



Scheme of the laboratory equipment for testing of grout flow in discontinuities

1 pump
2 control manometer
3 pressure hose
4 pressure medium
5 pressure cylinder
6 piston
7 grout
8 injection jack
9 press
10 sealing
11 rock sample
12 fissure
13 injection hole

Fig.1

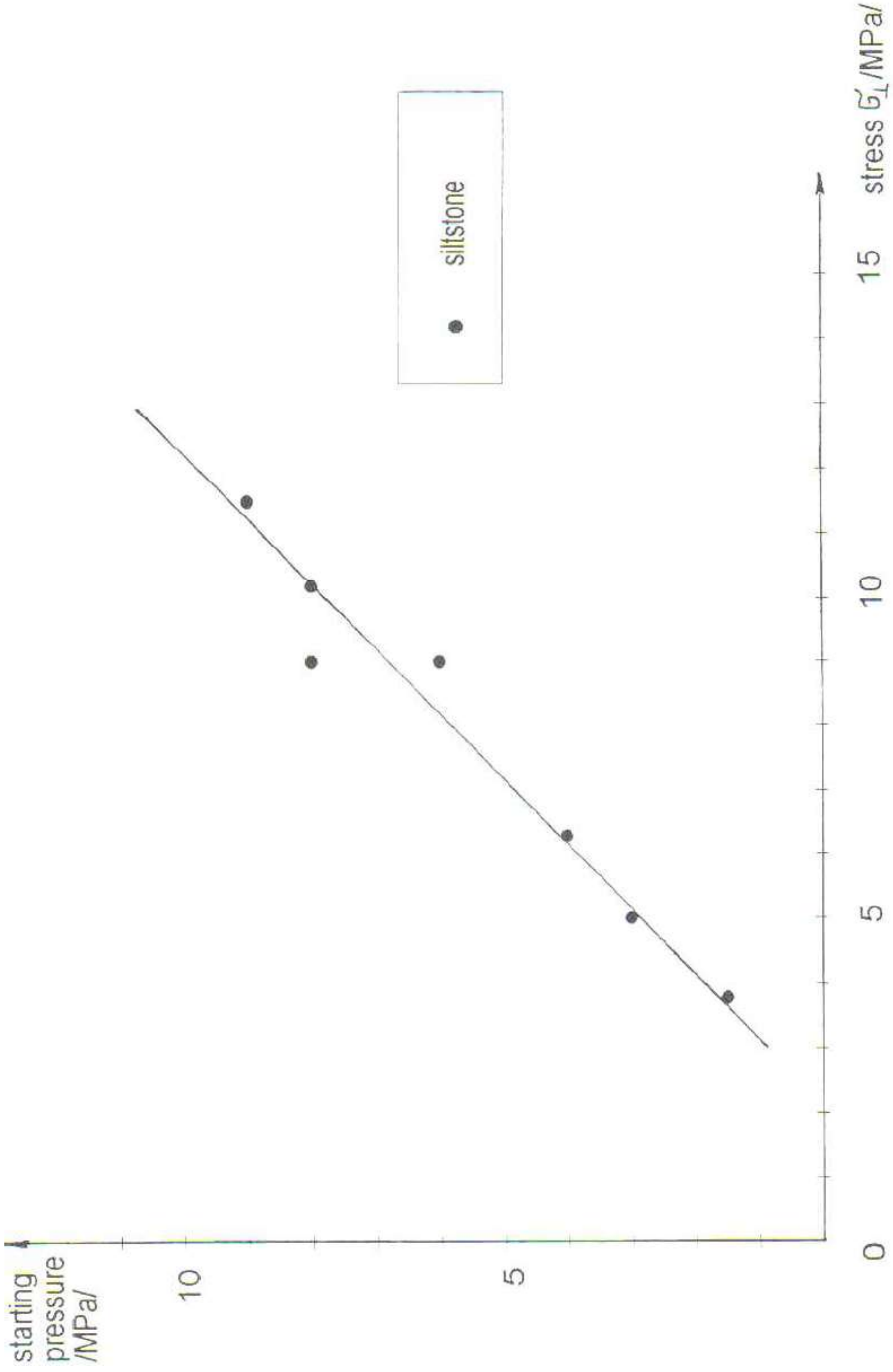


Scheme of the laboratory equipment for testing of grout propagation in porous materials.

1 two-component pump
2 grout
3 control manometer
4 pressure hose
5 sample box

6 cover
7 venting
8 main in box bottom
9 main in perforated tube
10 rock sample

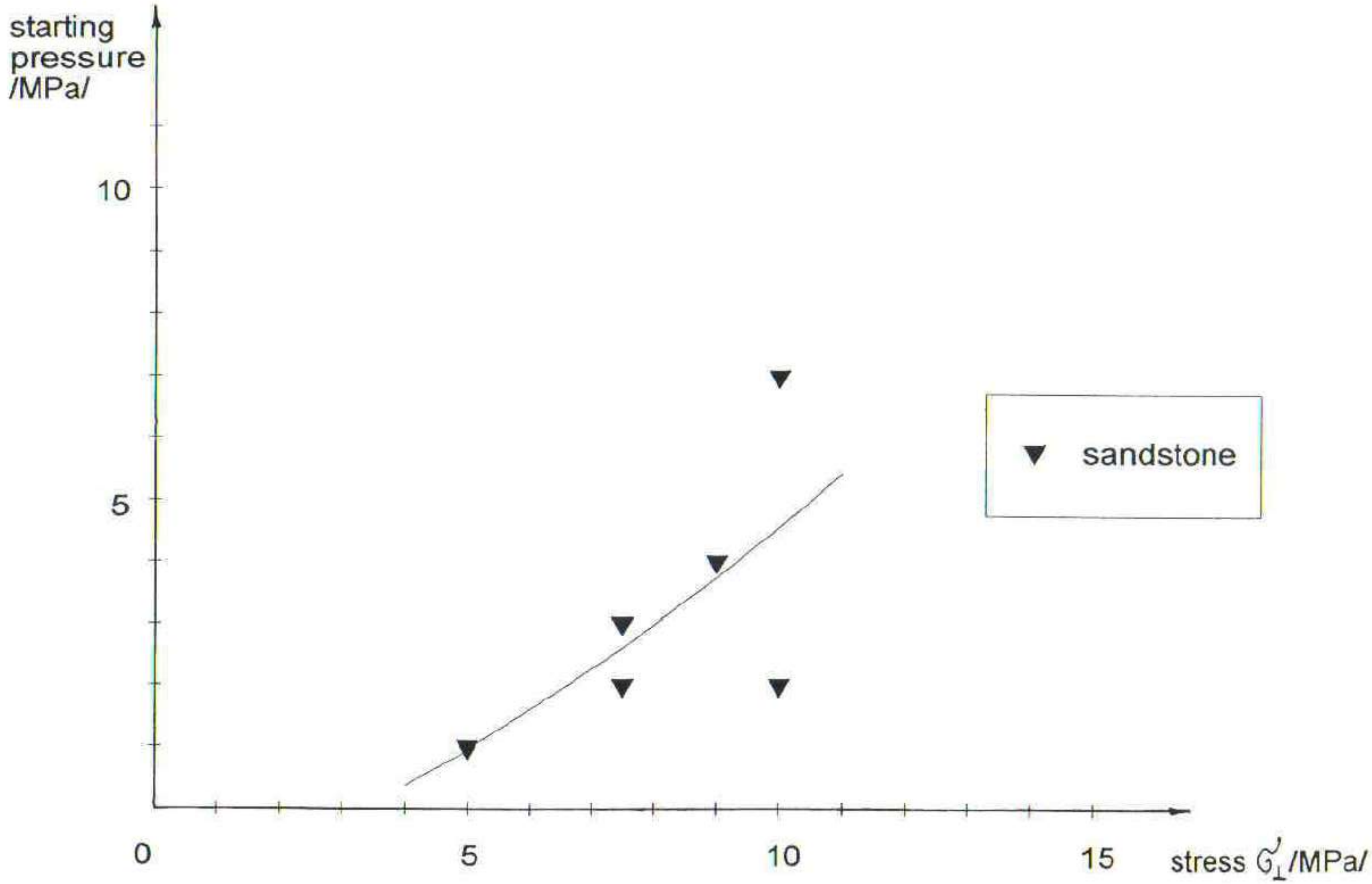
Fig.2



Grout viscosity 100 mPa.s

Dependence of starting pressure on stress in rock sample.

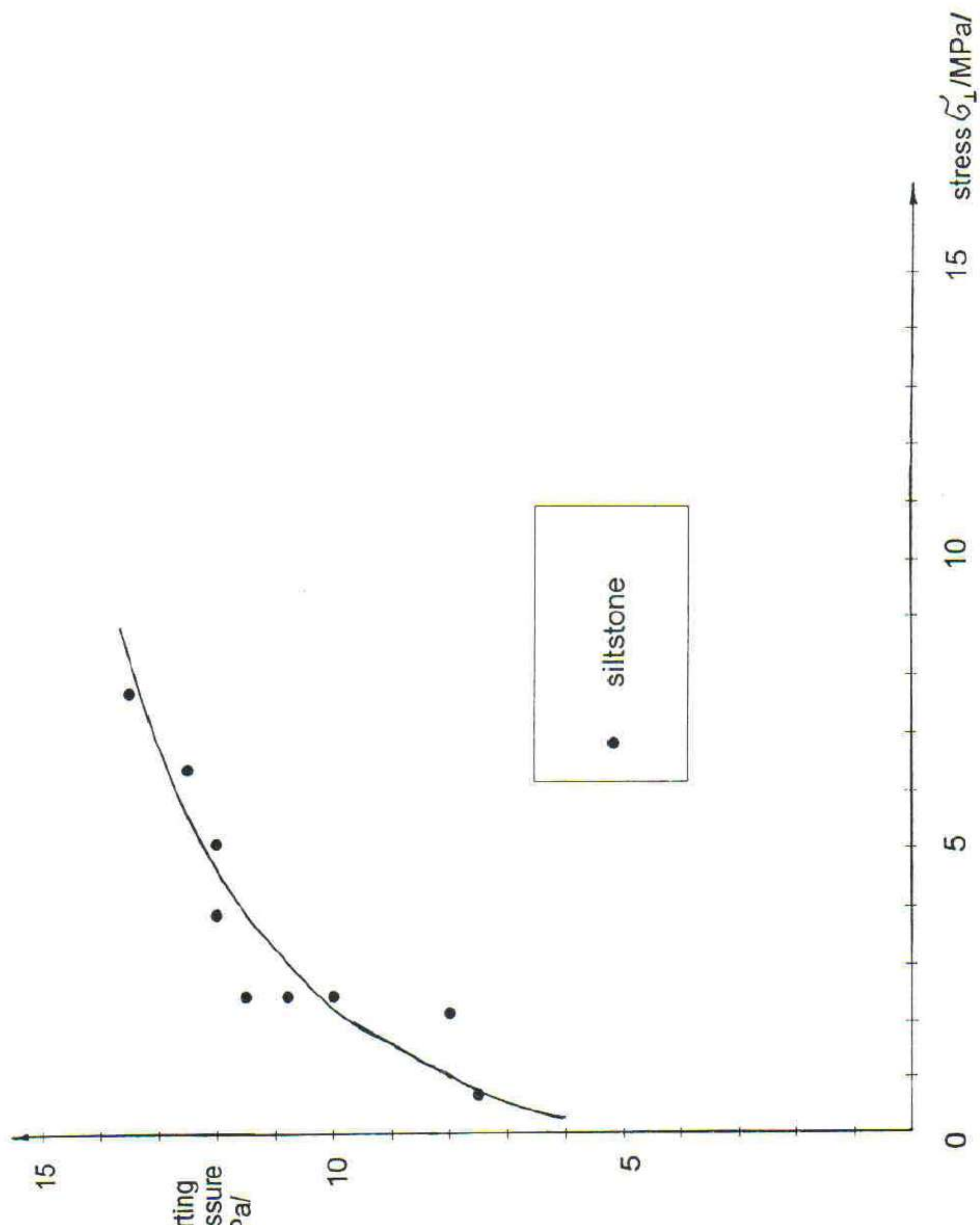
Fig.3



Dependence of starting pressure on stress in rock sample.

Grout viscosity 100 mPa.s

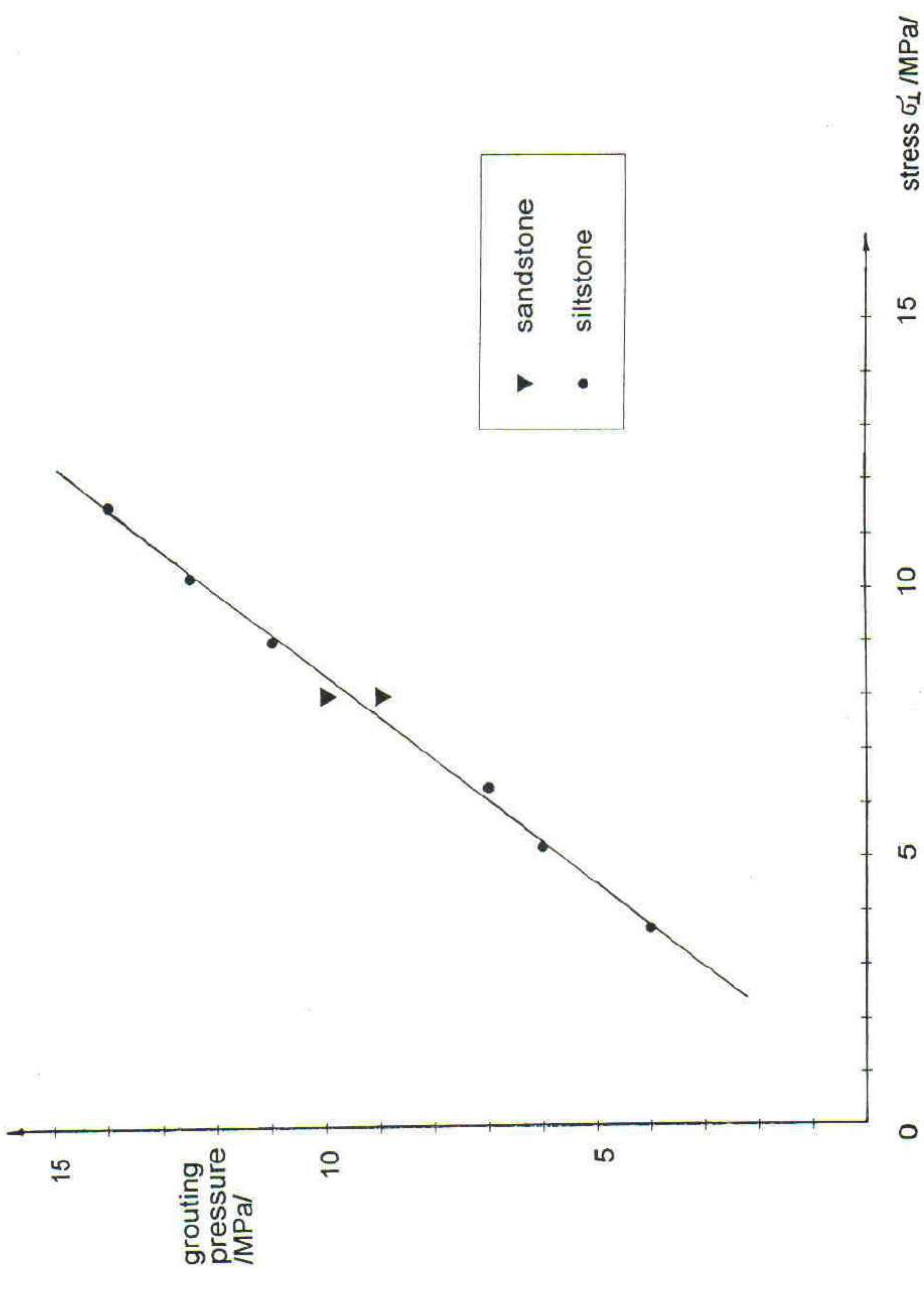
Fig.4



Dependence of starting pressure on stress in rock sample

Grout viscosity 500 mPa.s

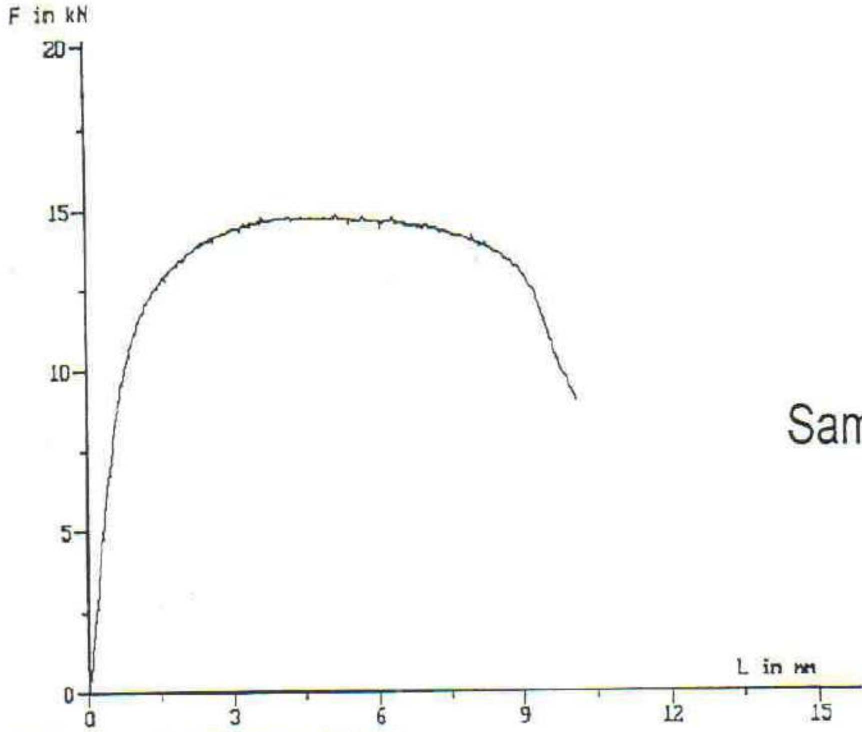
Fig.5



Dependence of grouting pressure on stress in rock sample.

Fig.6

Grout viscosity 100 mPa.s



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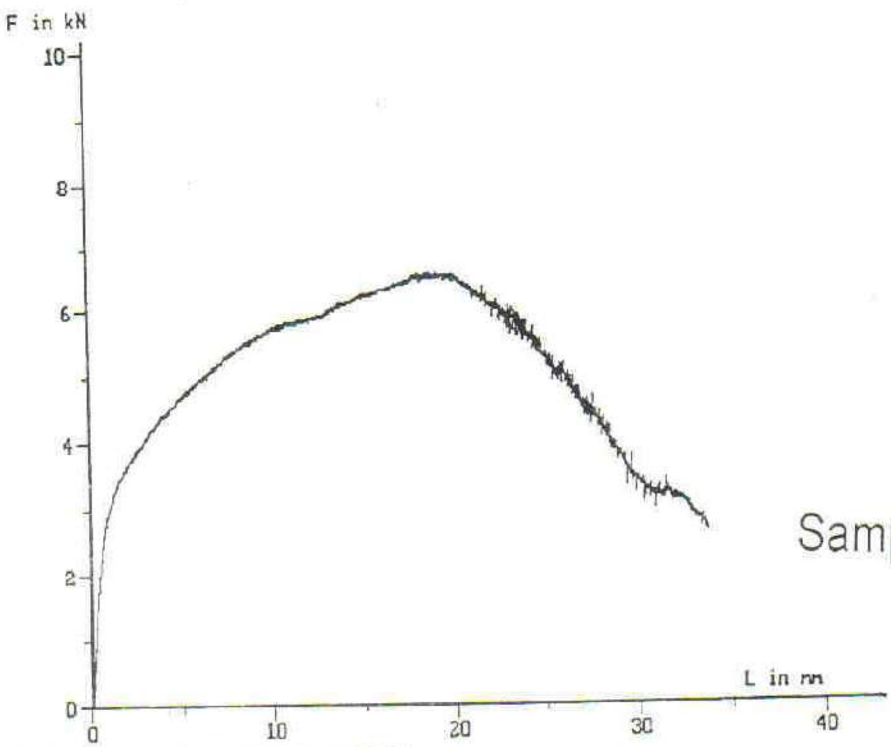
Sample A



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Sample B

Uniaxial strength test of grouted sand.