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Polymeric Materials for Underground Support

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POLYMERIC MATERIALS FOR UNDERGROUND SUPPORT

by

J. C. Franklin,[1] J. E. Fraley,[2] R. E. Burnham,[3] and L. W. Brandt[4]

ABSTRACT

The Spokane Mining Research Center of the Federal Bureau of Mines is placing major emphasis on chemical stabilization as part of the ground support program. Development of polymeric material suitable for bonding rock fractures around the mine opening is one phase of the program. Some of the problems that must be considered are viscosity, applicability, adhesion, cure times, strength, toxicity, and flammability.

Epoxies and polyesters were investigated, but shrinkage in polyesters caused redirected effort toward epoxies. Test results with the latter showed that bonded fractures in mine-roof strata were stronger than the virgin rock.

Further tests showed that polymeric materials have good potential for bonding, and in conjunction with polymer roof bolts, are expected to result in an economic and useful new support concept.

INTRODUCTION

The rock structure surrounding a mine opening characteristically contains in-situ fractures, which provide natural failure initiation points. A number of different systems have been used to support openings in rock and to prevent failure. Typical examples are bolts, sets, posts, and arches.

In bedded rocks surrounding or including deposits such as coal, experience as well as analytical/numerical calculations have demonstrated that shear stresses exist in the planes parallel to the bedding planes, particularly near the rib. Such stresses may be relieved by interlaminar slip--the movement between two adjacent planes that are approximately parallel. In bedded deposits, the in-situ cracks are usually preferentially oriented parallel to the laminate structure of the rock, due to shear stresses or in a normal direction due to bending stresses. If these cracks can be bonded together,

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the rock opening can become a self-supporting structure with properties similar to the original unfractured material.

The concept of chemical impregnation to strengthen mine rock dates back to the 1950's (1, 5-6).[5] Those early investigations revealed that polymers could be injected into rock strata and that the rock was strengthened as a result. Other laboratory tests on sandstone and tuff rock demonstrated that polymers can be injected into the pore structure, greatly increasing the rock strength and elastic properties (3).

The Bureau of Mines Spokane Mining Research Center objective is to select the appropriate polymers for successful injection and cementation. Most of the emphasis has been on roof rock usually found in coal mines (shale) although the technology being developed is applicable to other rock.

The desirable characteristics that an injected polymer should possess are listed. These characteristics are not rigid objectives, but are properties that the authors believe to be necessary to reach the objective. As the program develops and as new health and safety regulations are introduced, this list will require modification.

1. A pot life of at least 5 minutes to allow for injection.

2. A minimum bond strength of 300 psi to insure that the tensile strength of the bonded interface is at least as great as the tensile strength of the remainder of the rock.

3. A 300-psi bulk tensile strength to match the bond strength.

4. A wet-or-dry bonding capability to meet mine-rock conditions and the 300-psi tensile strength.

5. A thin-film penetration and bonding capability to insure bonding of 5- to 20-mil cracks.

6. A fast-set characteristic in the thin-films to obtain at least 10 percent of the minimum bulk and bond strength of 300 psi in 10 to 15 minutes, 50 percent of this final strength in 3 hours, and 90 percent in 8 hours. This characteristic provides acceptable support strength before the next mining cycle.

7. A stress-strain characteristic curve that is nonbrittle when compared with rock. The material should undergo 25-percent elongation before failure.

8. The visco-elastic-plastic properties shall prevent creep failure during a continuous tensile loading of 300 psi.

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[5] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

9. The material must achieve its capabilities within a relative humidity range of 20 to 100 percent at temperatures ranging from 50° to 60° F.

10. The material should have a low viscosity, preferably less than 100 cps.

11. Material shrinkage shall not cause pulling away from the bonded surface.

12. Environmental characteristics, such as odor, toxicity, fuming, pyrolysis, shall not cause health, safety, or tolerance problems. These factors, due to presently ambiguous or nonexistent regulations, have yet to be determined.

13. Small amounts of spillage are inevitable during application; therefore, the polymer must have a flashpoint greater than 140° F.

This report presents the in-house and some contract research laboratory work, as well as the results of preliminary impregnation field tests conducted on selected polymers.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of John Corwine (formerly of the White Pine Copper Mine Co., White Pine, Mich., and now with the Bureau of Mines in Washington, D.C.) and Nick Bada, of the White Pine Copper Mine Co., for the many hours of help during the field experiments. We would like to also thank the White Pine Copper Mine Co. for allowing these tests to be conducted in their mine. Other people contributing to the field experiments are Harold Thomas, Robert Thompson, Robert Simpson, John Habberstad, and Lee Nuzum, all of SMRC. This work could not have succeeded without the efforts of all these people.

LABORATORY EXPERIMENTS FOR IMPREGNATION

Test Procedures

It is impractical to test all of the candidate materials underground. Therefore, extensive laboratory tests, using the list of desirable properties as a guide, are performed on the materials in order to select the ones most likely to succeed underground. Each system is first optimized regarding gel and cure times. The ratio recommended by the manufacturer is tried first, then the ratios are changed and additional chemicals added to modify the system for more rapid gel and cure times. The tests are performed at room and simulated mine conditions for both bulk and thin-film quantities.

After obtaining satisfactory timing, the materials are tested for adhesion to both wet and dry shale strata. This requires cutting 2-inch cubes parallel to the bedding of the material. These cubes are fractured, bonded with the candidate material, and retested. Tensile testing is accomplished at various cure times ranging from 2 to 48 hours.

After breaking, the surface of both pieces is examined to determine whether the break occurred on the bonded surface or in a new area. The surface is then rebonded and cured with the same polymer material at average mine temperature and humidity, and the test is repeated.

Another important test for long-term creep was conducted by the Washington State University (8). It is performed by bonding together 1/4-inch cubes, with metal pull tips bonded to both ends. The materials are cured at mine temperatures. They are then hung on a rack with 20 pounds of dead weight attached to the bottom, making an equivalent stress of 320 psi for creep

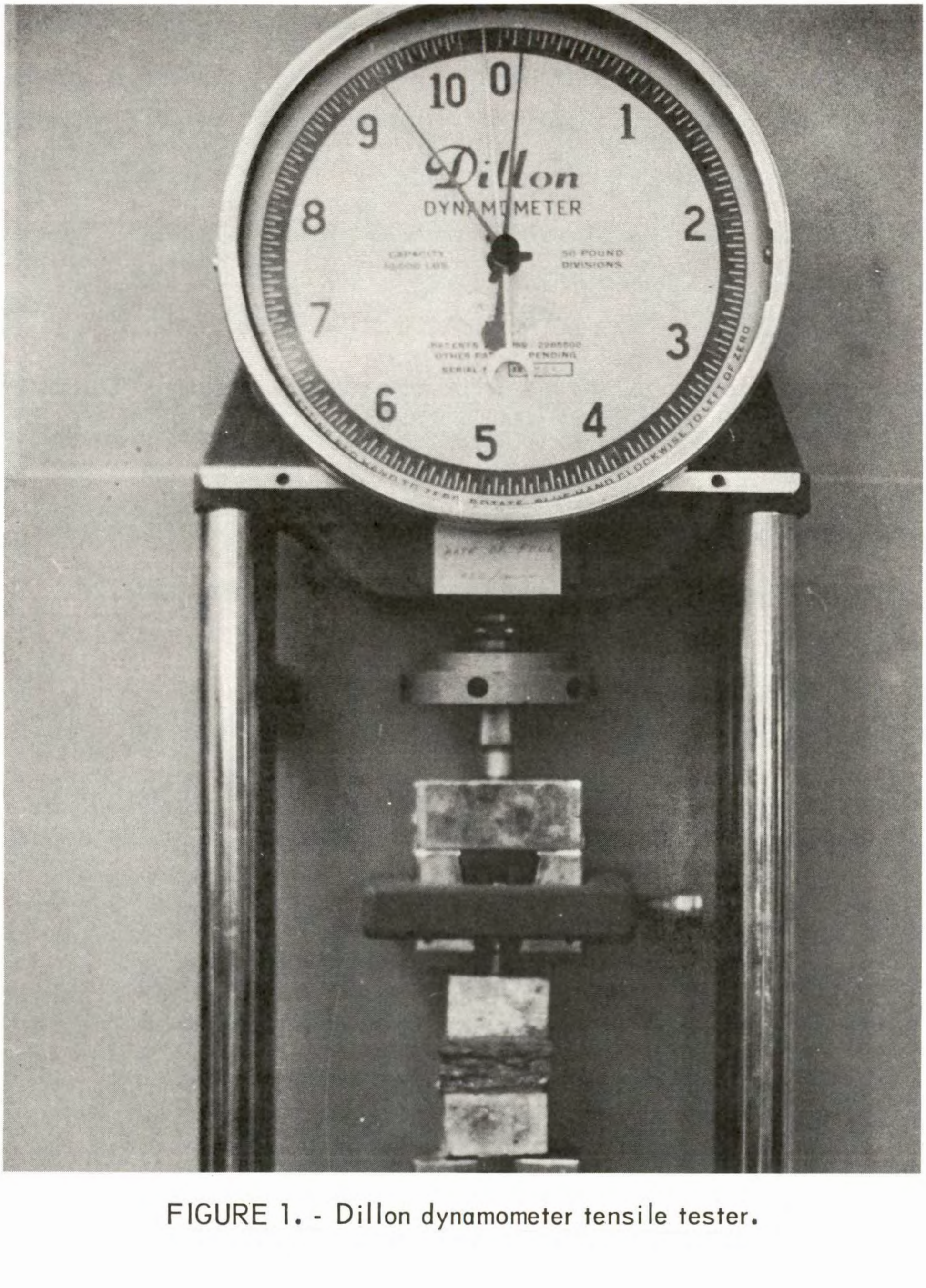

FIGURE 1. - Dillon dynamometer tensile tester.

testing. Some of these materials have been suspended longer than 6 months without failure. Direct tensile creep strength of the bond material was specified as a requirement in the list of desirable properties.

The tensile strengths discussed in tables 3 through 7 were all measured in the following manner. The 2-inch cubes of shale were bonded to two aluminum blocks and connected to the Dillon[6] dynamometer. This tester pulls on the rock cube at a rate of 0.052 inch per minute. As the pull increases, the tensile load is indicated on the dial gage (fig. 1). When the rock breaks, the reading is divided by 4 to give the tensile strength in psi.

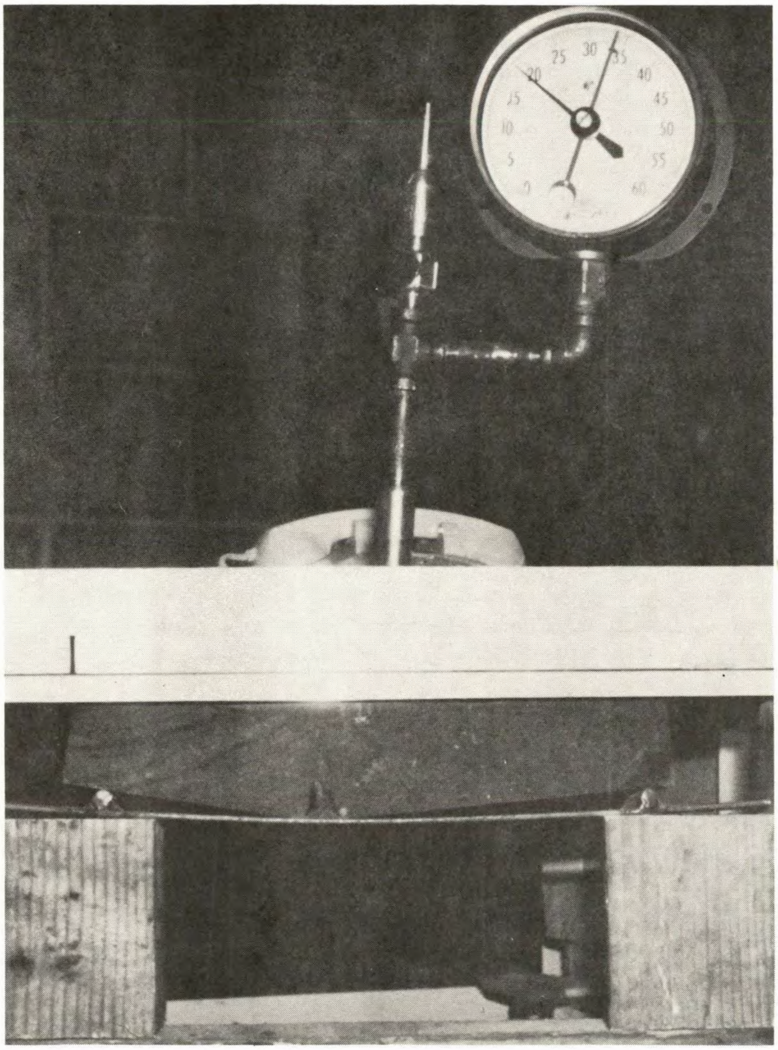

FIGURE 2. - Uniform flexural test apparatus.

In a mine the overhead roof rock is loaded by body forces, causing bending stresses to exist after the values have been removed; that is, the roof rock is loaded as a beam. The beam end conditions can vary from nearly a fixed condition to an essentially simply supported condition.

To simulate the body loading in the laboratory as closely as possible, without doing centrifuge testing, a uniform load flexural test apparatus (fig. 2) was used.

Operation of the simply supported apparatus is as follows: A rock specimen is inserted into the test apparatus and pushed up into the retainer. The beam is then supported in this position by the support bar. Pressurized nitrogen gas is bled into the expandable bladder until the beam breaks. The pressure is recorded on the pressure gage. Using equation 1, the stress on the beam is calculated.

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[6] Reference to specific equipment does not imply endorsement by the Bureau of Mines.

$$\sigma = \frac{Mc}{I} , \tag{1}$$

where M = moment, inch-pounds,

C = distance from the neutral axis to the outside surface of the beam, inches,

I = area moment of inertia, inches^4.

For example, tests were performed by fixing both ends of 2- by 2- by 11.75-inch slabs of volcanic tuff and applying a uniform pressure to the top of the sample. The pressure applied was increased until failure occurred and the pressure noted. Since the sample was fixed on both ends and the load applied was uniform, the strain occurring on the bottom center surface of the rock was calculated by

$$\sigma = \frac{p\ell^2}{4h^2} , \tag{2}$$

where p = pressure, psi,

ℓ = length, inches,

h = thickness, inches.

Other tests for adhesion to wet surfaces, adhesion to dirty surfaces, and penetration of thin cracks are somewhat arbitrary and are performed by placing the polymer on a wet, dirty, or fractured rock. Forced injection was tried on competent (visibly unfractured shale) and incompetent rock. The specimens are drilled or broken to observe by eye or light-sensitive dyes the amount and type of penetration and adhesion. Every attempt is made for adequate and appropriate tests to be performed to indicate the possible degree of success of the objective, which is to bond in-situ fractured and poorly bedded rock to form a competent structural support segment.

Materials for Impregnation

To select possible impregnation material candidates, a large number of manufacturers were contacted and their literature reviewed. Materials that had published properties somewhat akin to those outlined in the properties list were ordered for laboratory testing. A potential polyester, made by American Cyanamid Co.[7] was Laminac resin EPX289-4, which is a water-extendable styrene monomer. This system was modified using 50 percent EPX289-4,

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[7] Products referred to in this report are used primarily to identify the basic substance, and if the material fails our test, it does not indicate failure to meet the specification listed by the manufacturer. The bonding of shale rock under conditions described here is most difficult. Therefore, the Bureau of Mines does not imply that these materials are not good for ordinary usage nor does the Bureau imply endorsement of those materials which were successfully tested.

30 percent monochlorostyrene, and 20 percent trimethylolpropanetrimethacrylate. Later EPX295-1 was optimized in the same manner as EPX289-4.

The EPX295-1 had a very low viscosity (<100 cps at 67° F) and penetrated rock very well. Capillary effect caused the monomer to travel vertically in cracks up to 3 inches in 1 minute. Figure 3 shows the area penetrated in the rock. The darker areas are the monomer. The grooves were caused by the saw blade.

The EPX295-1 system was fairly good except for its low flashpoint, emission of styrene odor during injection, use of methlethylketone peroxide catalyst, and its shrinkage. The gel and cure times were excellent, and the bond strength was good.

Another polyester system investigated was Interplastics Co. Resin 1038-16 (table 1), which had the styrene odor masked. Even so, the odor was present during the reaction.

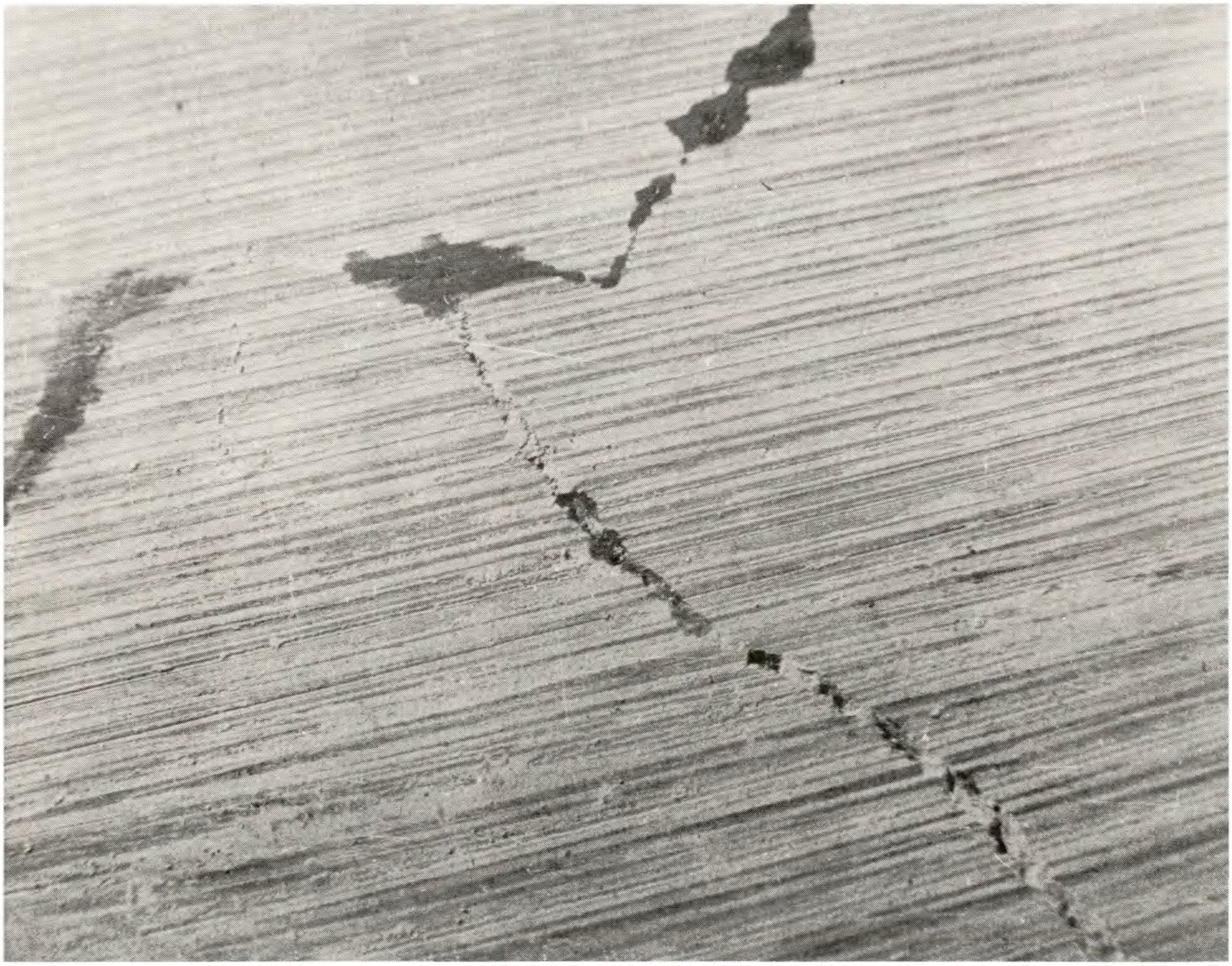

FIGURE 3. - Penetration of monomer into shale rock.

TABLE 1. - Tensile data of Interplastics Resin 1038-16[1]

Cure time, hours	Tensile strength, psi[2]	Cure time, hours	Tensile strength, psi[2]
0.5	21.9	3.5	>147.8
1.0	>87.7	12.5	>163.0
1.5	>70.5	17.5	>369.6
2.0	>119.0		

[1] The values reported in table 1 are the average of five tensile tests using the 2-inch cube samples.

[2] If the break occurred on the bonded surface, no notation was made. If the break occurred at a new location, the value was reported with the notation >.

The samples in table 1 were numbered, and the change in strength with the change in cure time for each rock could be compared with previous breaks. The samples seemed to increase in tensile strength before the rock starts loosening in all the bedding planes. The resin itself is stronger than what this table shows. The resin has a 20-minute gel and 30-minute cure time at mine temperature and humidity.

The results of using EPX295-1 as an impregnant in flexural tests of volcanic tuff is shown in table 2. The average tensile strength was about 275 psi for the material as compared with the flexural strengths shown in the table. This test method was used to more closely simulate the uniform load the roof is supporting.

TABLE 2. - Uniform load flexural data using volcanic tuff as test rock

Sample No.	Penetration depth, inches	Pressure applied, psi	Stress, psi	Average stress, psi
Control.............	-	27.0	233.0	-
Do................	-	22.0	189.8	-
Do................	-	17.0	146.7	192.5
Do................	-	26.5	228.9	-
Do................	-	19.0	163.9	-
1[1]..................	0.50	44.0	379.7	-
2[1]..................	.56	37.0	301.5	-
3[1]..................	.50	23.8	205.4	-
4[2]..................	.44	23.3	201.1	-
5[2]..................	.44	36.8	317.5	-
6[2]..................	.44	38.0	327.9	-
7[1]..................	(3)	34.0	293.4	-
8[1]..................	(3)	32.7	282.2	292.5
9[1]..................	(3)	35.0	302.0	-

[1] No catalyst used. EPX295-1 monomer oven cured at 150° C.

[2] Catalyst-cured samples.

[3] Completely saturated with monomer.

Because polyester systems have shrinkage and noxious vapor problems, the in-house investigation was changed to epoxy systems. Numerous ones were studied, with several failing to meet any of the impregnation requirements; therefore, they are not discussed. Only the systems with promising factors are tabulated.

One of the systems tested was Celanese Resin Co. Epi-Rez 510, Epi-Cure 879, with water added; the ratio of these components was 45:33:22, respectively. This system had a bulk cure time of 20 minutes at both room and mine temperature and humidity. During gelling, the resin expanded and flowed out of the mixing cup. The viscosity was 1,500 cps just after mixing.

Table 3 gives the tensile data for the Epi-Rez 510, Epi-Cure 879, and water after various curing times. This resin reached 32 percent of its final strength in 2 hours and 80+ percent in 24 hours, regardless of the temperature.

TABLE 3. - Celanese resin tensile data, psi

Sample No.	2-hour cure at room temperature	24-hour cure at room temperature	72-hour cure at room temperature	24-hour cure in weatherometer
1	24.0	38.0	>70.0	75.0
2	63.0	199.0	>225.0	115.0
3	19.0	>194.0	(1)	>165.0
4	28.0	175.0	>169.0	>194.0
5	25.0	115.0	188.0	>156.0
6	27.0	>163.0	>228.0	>150.0
7	74.0	269.0	(1)	>256.0

[1] No test run.

Another system studied extensively was a two-component epoxy called Pro-Bond Amber Topping, produced by Pro-Tex Industries. This material had excellent adhesion to both wet and dry shale when the samples were cured at mine temperature and relative humidity. The results for Pro-Bond are listed in a tabulation. Each value reported is the average of seven samples. Because of the high gel and cure times, the ratio was changed from two parts resin to one part hardener to other combinations. No ratio was found that gave good tensile strengths in the required time. This system will be investigated again using other catalysts.

Pro-Bond test data, psi[1]

Dry shale:		Wet shale:	
1 hour	1	1 hour	(2)
3 hours	2.5	3 hours	(2)
8 hours	46.0	8 hours	(2)
24 hours	>516	24 hours	>229
48 hours	>560	48 hours	>280

[1] Viscosity at room temperature, 900 cps; bulk gel, 27 minutes; bulk cure, 40 minutes.

[2] No test run.

An epoxy, Sta-Crete No. 850 made by Sta-Crete Inc., was found to be like the Celanese Epi-Rez 510, mentioned previously. The gel and cure times were reduced with the addition of water. The Sta-Crete material gave favorable results, as shown in table 4, when tested with shale rock.

TABLE 4. - Sta-Crete test data

Material	Bulk gel, minutes	Rock condition	Strength of Sta-Crete No. 850, psi[1]			
			3 hours	5 hours	7 hours	16 hours
Sta-Crete.......	30	Wet......	6	>200	>300	-
Do............	30	Dry......	12.5	80	375	1,950
Sta-Crete + 20 g H_2O.	8	Wet......	12.5	70	87	-
Sta-Crete + 10 g H_2O.	9	Wet......	6	108	-	-
Sta-Crete + 10 g H_2O.	9	Dry......	6	212	-	-

[1] Temperature, 55° F; relative humidity, 80 percent +.

NOTE.--Blank spaces indicate no test run for the specified time period.

Table 5 lists various polymers that have been started and not completed or eliminated, because they do not meet the requirements listed previously. More work will be done at a later date to see if some of them can be modified to meet the requirements.

TABLE 5. - Miscellaneous systems listed with lab work incomplete

Product trade name and manufacturer	Catalyst used	Gel time, minutes	Cure time, minutes	Tensile data, pounds					
				2 hours	3 hours	4 hours	8 hours	24 hours	48 hours
Refco R811 (King Fiberglass)....	H903.1	6	7	10	-	>74	>81	>167	666
Epon 812 (Shell)	H903.1	5	9	-	33	>46	>32	-	-
Refco 812 (King Fiberglass)....	H901.1	5	7	-	-	-	107	396	-
Concressive 1...	-	-	-	-	-	760	-	280	85
Devcon 2316-1 (Devcon Corp)..	-	8	-	-	-	-	-	--	667
Devcon 2316-2...	-	9	-	-	275	-	>159	1,025	-
Devcon 2316-3...	-	65	-	-	-	-	-	665	-
Ultra-adhesion..	-	-	-	-	-	-	-	>550	-

NOTE.--Blank spaces indicate no test run for the specified time period.

FIELD EXPERIMENTS FOR IMPREGNATION

All field tests for in-house work were at the White Pine Copper mine, White Pine, Mich. This mine was selected because its overhead strata is similar to a typical coal mine and because the fire hazard was lower. The average mine temperature is around 57° F with a relative humidity of

90 percent or higher. The company uses diesel-operated equipment; therefore, the roof is oily, wet, and dusty.

Three different underground experiments were conducted at White Pine. The impregnation-test equipment is shown in figure 4. The equipment uses compressed nitrogen, controlled by a regulator up to 125 psi. The gas enters the injection pot containing a wax Dixie cup, holding 250 milliliters of resin, and forces the fluid out. The injector plug is anchored into the back by a

FIGURE 4. - Liquid-polymer injection equipment.

rubber washer, which is compressed, forming an air-tight seal in the predrilled hole. There is a check valve located on the top of the anchor bolt to prevent the fluid from draining back out of the hole. Once the resin has cured, the injector plug can be removed and everything reused, except the check valve. The equipment has quick-disconnects so that rapid changes of resin cups can be made. This allows more than one cup to be injected into any given hole. The resin is injected into the roof until leakage is observed or until the hole refuses to take additional material. This simple system proved to be effective for our initial underground field tests.

The first experiment used American Cyanamid water-extendable EPX295-1 polyester diluted with monochlorostyrene. The material was injected into 1-inch-diameter holes drilled 1 foot into the back. Wooden dowels were placed inside the holes to reduce the volume of fluid needed to fill the holes. It was found that small cracks, less than 0.001 inch wide, and voids could be penetrated and filled. Due to shrinkage and poor bond characteristics, however, subsequent core samples broke at the bonded surface.

For the second test, two rows of 1-inch-diameter holes, 1-foot deep, were drilled on 2-foot centers separated by a row of roof bolts. These holes were used as the injection port for both air and resin and to detect leakage from an adjacent hole during its injection.

Before injection was started, tests were run to determine whether the roof was tight or had any cracks within the 1-foot depth of the injection port. This was done by injecting air into one port and using hot-film logging measurements to detect air coming out other holes. Through this test we found a crack that was fairly uniform throughout the test area, about 10 inches into the roof. The test showed that the flow of air could be measured as far as 20 feet away from the injection port. Equipment and procedure used are described by Chan (2) and Thomas (7).

Four different kinds of epoxies were injected into various holes. Each varied in gel and cure times, quantity, and bond strength. The first epoxy was Pro-Bond Amber Topping from Pro-Tex Industries. This is a basic epoxy, using two parts resin to one part hardener, curing at mine humidity and temperature in 1 hour and 15 minutes. Viscosity during injection was 800 cps. In one injection, 1,800 cubic centimeters of this material was injected as fast as it could be mixed, with no indication of leakage. The location was close to the rib and the corner of the pillar. When core samples were taken in this area, no resin was found; therefore, it probably traveled upward. A total of 1,000 cubic centimeters of resin was injected in three other holes. Core samples showed excellent resin bonding in cracks up to 20 mils wide.

The next epoxy was a water-extendable material from Celanese Coatings Co. This epoxy consisted of 100 grams of Epi-Rez 510, 72 grams of Epi-Cure 879, and 25 grams of water. At mine temperature this material had a viscosity of 1,300 cps with a cure time of less than 4 hours in thin-film. A total of 850 cubic centimeters was injected into one hole. Through visual inspection, core samples showed good bonding properties.

The third was a commercial epoxy called Penntrowel, using six parts resin to one part hardener. The viscosity at mine temperature was 90 cps and the cure time was about 4 hours in thin-film. Only one hole was injected using 900 cubic centimeters before a leak appeared in the roof about 2 feet away. Some of the core samples taken in this area showed good penetration, but the resin was still tacky 48 hours later. This indicated improper mixing of resin and hardener because other cores from the Penntrowel area showed good bonding.

The fourth epoxy was modified by Washington State University (WSU). It consisted of 170 grams of Epon 828 (Shell Chemical Co. resin) with 30 grams of cresyl glycidyl ether (CGE) mixed with 22 grams of diethylenetriamine (DETA) and 20 grams of furfuryl alcohol (FA). This produced a viscosity of 90 cps and reached 100 percent strength in 4 hours at room temperature. At mine conditions the viscosity was under 300 cps with 100 percent strength in 6 hours. A total of 2,140 cubic centimeters was injected into five holes. Leakage was detected during two injections. Core samples showed good bonding and good filling ability in cracks 1 to 20 mils wide. Of the systems tested during this field test, this modified epoxy comes the closest to meeting the objectives outlined previously. No tensile tests were run on any cores. The cores

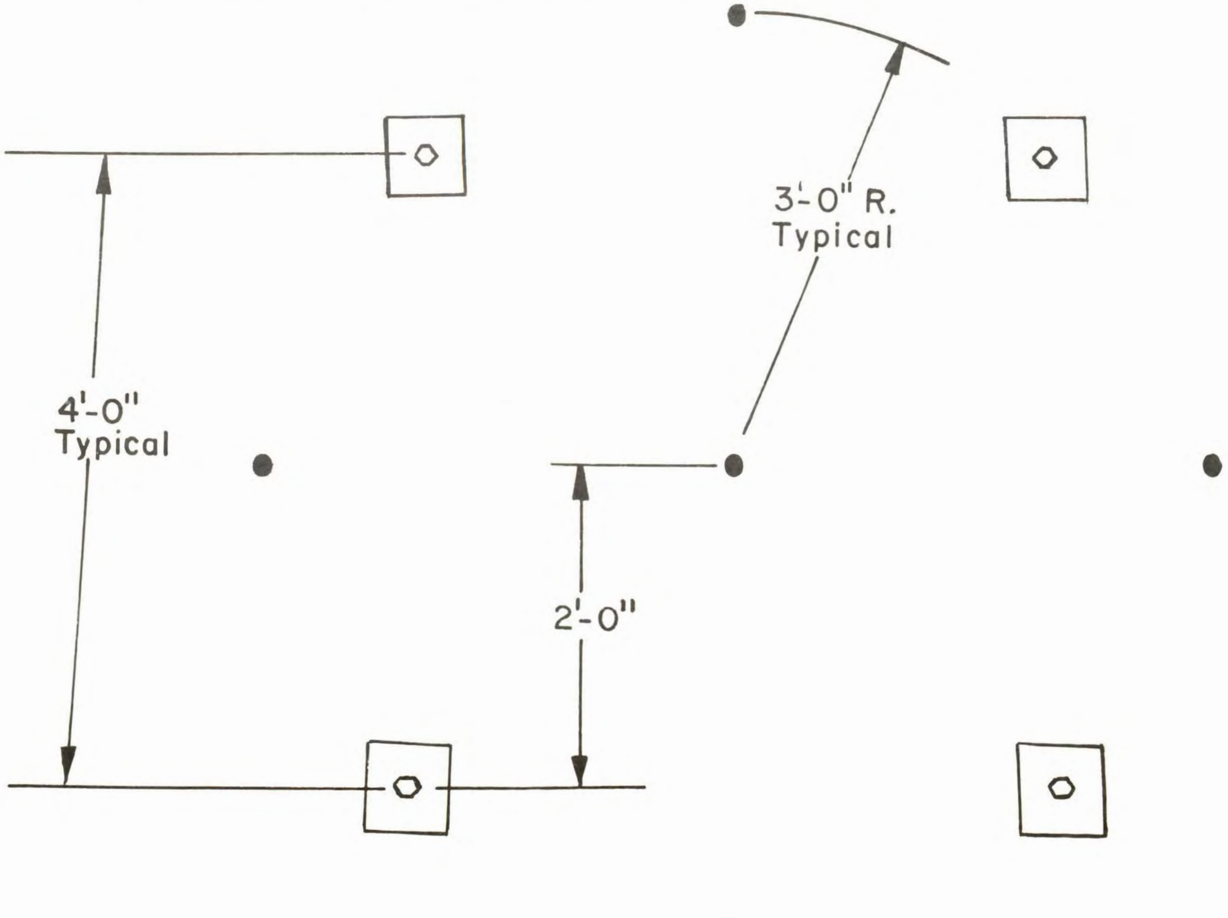

FIGURE 5. - Test hole pattern for injection.

were examined visually and with magnification to insure no polymer shrinkage. With poor bonding the cores would shear during the cutting of the core samples.

On the last field test at White Pine, the injection port was changed somewhat. As seen in figure 5, the pattern consisted of five holes on 3-foot centers with the center hole centered between four roof bolts. This allowed eight areas for the injected resin to leak from the roof. The center hole was used as the main injection port, though in some cases, the outside holes also were used.

Before injection, air pressure was applied to the center hole. The airflow was measured in the four outside holes and showed that two sets of holes near the pillar were too tight for impregnation and required extra drilling. Hot-film flow logging is a useful tool for determining where impregnation is needed without wasting time and resin.

Table 6 lists the epoxy and polyester modified systems used in the last field test. It gives the WSU identification numbers and chemical composition in parts by weight for each system.

TABLE 6. - Resins used for field test 3

Number	Chemicals used	Parts by weight
	EPOXY RESINS	
21-A	85/15 Epon 828/cresyl glycidyl ether (CGE).........	100
	Furfuryl alcohol (FA)............................	10
	Diethylenetriamine (DETA)..........................	11
A-10	85/15 Epon 828/CGE.................................	100
	FA...	20
	Accelerator (DMP-30)...............................	12
	DETA...	11
F 8	92/8 Epon 828/CGE..................................	100
	FA...	20
	DMP-30...	12
	DETA...	11
	POLYESTER RESINS	
2	Chlorostyrene (53 pct) + Hetron (47 pct)...........	100
	Hetron (34 pct) + CCl_4 (66 pct).................	100
3	Chlorostyrene (53 pct) + Hetron (47 pct)...........	100
	Hetron (34 pct) + CCl_4 (66 pct).................	50
	Hetron (42.5 pct) + FA (57.5 pct)..................	50

WSU resin 21-A was the same modified system as used in field experiment 2, and again showed excellent adherence to the shale rock. In the three sets of holes, the first was tight and only took 360 cubic centimeters of resin; the second and third sets took 1,000 and 1,300 cubic centimeters, respectively, before leakage occurred in the roof. Core samples from the second and third holes showed good penetration and crack filling along with good bonding. This resin meets all of the criteria detailed in the introduction except its gel and cure times at mine conditions.

WSU system A-10 also was injected into three holes for a total of 4,200 cubic centimeters; bonding was good. Gel time was about 40 minutes and hard cure was 50 minutes in bulk quantities.

The last epoxy resin, WSU F-8, was injected into three holes with a total of 3,800 cubic centimeters with no leakage from the back. Gel and cure times were similar to those of A-10. There was good bonding in cracks up to 20 mils thick.

Both polyesters were injected into one hole each. Because of the tightness of the back, only 300 cubic centimeters of each was used. The only core samples were overcores of the injection hole to check for shrinkage. In both cases shrinkage was almost nonexistent. These two polymers should be tested again. Both exhibited good gel and cure times with minimum shrinkage. They could prove to be excellent materials for impregnation.

CONTINUATION WORK

A Bink's formulator "G," two-component spray/pour apparatus is undergoing modification to pump larger quantities. The machine will be used in a major test of polymeric materials for impregnating the roof.

The research to develop a method for placing pumpable, fiberglass-roving-reinforced roof bolts should be tried simultaneously with impregnating the roof and back (4). Special equipment will be needed to supply the fiberglass roving and inject the polymeric material at pressures around 100 psi. The combination of liquid roof bolt and rock impregnation should produce a superior support system. Equipment design is in the planning stage, and prototype apparatus should be ready in the near future.

SUMMARY

Laboratory work shows a potential for rock strengthening by injecting polymeric material into rock strata and voids. Materials have been developed with necessary viscosity, adhesion, handling characteristics, and physical properties to apply in the laboratory. Also, preliminary field tests results show that polymeric materials fill voids and cracks in roof strata. It may also strengthen the roof as well, since the roof at White Pine is holding up, and no cave-ins have been reported so far. Roof falls in unsupported areas are common.

It now is necessary to develop better injection equipment and to modify the present material for better penetration and more consistent strength and adhesion. Indications are good for successful in-situ impregnation and adhesion in several different rock fracture or opening conditions.

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