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RAPID RUNWAY REPAIR STUDY

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RAPID RUNWAY REPAIR STUDY

SYRACUSE UNIVERSITY RESEARCH CORPORATION
MERRILL LANE, UNIVERSITY HEIGHTS
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This report describes a series of tests to evaluate a system for rapidly repairing airfield pavement using polymer concrete (synthetic polymer plus aggregate), thermally cured by microwave power. The technique, developed by the Syracuse University Research Corporation (SURC) for highway maintenance, uses a truck-mounted 50-kilowatt microwave generator to irradiate areas patched with polymer concrete. Test results indicate that the polymer concrete can be cured in a fraction of an hour, bonds well to old pavement material, is very

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strong, and possesses other qualities which make it naturally suited for airfield use.

FOREWORD

This report was prepared by the Syracuse University Research Corporation (SURC) under contract F08638-75-C-0010, job order 21042B18, with the Air Force Civil Engineering Center, Tyndall Air Force Base, Florida.

This report summarizes work done between May and August 1975. 1st Lt R. A. Bourquard was the former project engineer. Major George D. Ballentine is the current project engineer.

This report has been reviewed by the Information Officer (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

This report describes a nine-week research program sponsored by the Civil Engineering Center, Tyndall Air Force Base, Florida. The prime objective of the contract was to evaluate the use of microwave power in conjunction with polymer concrete (synthetic polymer plus aggregate) for expedient runway repair. The technology being evaluated was developed by the Syracuse University Research Corporation (SURC) for highway maintenance. The results of the research and testing indicate that the method is an efficient and fast way to repair damaged airport concrete with a high measure of success. During the testing, five patch areas were filled with polymer concrete and cured with microwave power.

The work conducted in this program has made extensive use of a mobile truck mounted microwave power unit and materials system developed by SURC for the Federal Department of Transportation and departments of transportation of five states. (Permission was granted by the original sponsors to use the microwave equipment for the AF testing program.) Even though the equipment was developed under another program, descriptions of the equipment and the associated microwave technology are presented in the present report in an appendix.

Also presented as an appendix is a discussion of the background technology pertinent to this method of pavement repair. This is included for a better understanding of the technological factors which have influenced the decisions made by the SURC research team.

In the evaluation testing conducted on core samples removed from the airfield pavement, the polymer concrete was found to compare very favorably with standard Portland cement concrete (PCC). As will be discussed in subsequent sections of this report, the compression strength exceeded that for PCC. Other properties also showed favorable comparisons.

Although the testing of this new approach to the rapid repair of runways has been brief, the results have been very favorable. Clearly the approach represents a potentially valuable tool for the military engineer.

SECTION II

MATERIALS

2.1 MONOMER/CATALYST

The polyester resin used in this project consisted of an unsaturated polyester resin (Reichold Chemical Company Polylite 31-001) which is of an unpromoted styrenated polyester category. The polyester portion of the resin consists of a 2:1 ratio of phthalic anhydride to maleic anhydride esterified with conventional glycols. The solid polyester material is dissolved in the cross-link styrene monomer by a 66:34 ratio and a sufficient quantity of inhibitors is added to yield acceptable storage life. The recommended shelf life of this resin is one year. This shelf life can be extended through the use of chemical additions, such as inhibitors, and through selection of protected storage conditions. A storage temperature of 20°C (68°F) is recommended since the storage life is inversely related to the storage temperature. However, one drum of the 31-001 resin has been stored at the SURC facilities at temperatures frequently ranging between 23.9° and 26.7°C (75° to 80°F) for approximately two years with no apparent detrimental effects.

The above polyester was mixed with 2 percent of a catalyst [benzoyl peroxide paste or MEKP (methyl ethyl ketone peroxide)]. Shelf life of this mixture is also temperature dependent. Tests conducted by SURC show that the catalyzed mixture can be stored in excess of one month at an ambient temperature of 21°C (70°F) and still be polymerized without detrimental effects. When stored at elevated temperatures, shelf life decreases in proportion to the storage temperature. Exposure to ultraviolet rays (sunlight) shortens the shelf life. It is, therefore, recommended that the mixture be stored in a cool (less than 21°C) dark place.

2.2 AGGREGATES

The aggregate used in repairing damaged areas consisted of a mixture of No. 1 and No. 1B (washed) limestone aggregate and kiln dust [27.5 percent of

No. 1, 62.5 percent of No. 1B (washed) and 10 percent kiln dust]. The sieve size distribution of No. 1 and 1B (washed) is shown in Table No. 1 and the sieve size distribution of the total composition (including kiln dust) is shown in Table No. 2. During investigations of the use of various aggregates it was determined that the addition of kiln dust (a by-product of Portland cement) to the aggregates increases compression strength and improves bonding of polymer to the aggregate. Portland cement could substitute for kiln dust since the primary function of the kiln dust is to provide the sieve fraction not present when a liquid cementing material is used.

The aggregate was air dried; no attempt was made to dry the aggregate at an elevated temperature. On the basis of previous investigations, SURC felt that the additional expense involved in oven drying of the aggregate was not warranted.

2.3 COMPOSITION OF PC (POLYMER CONCRETE)

The composition consists of 88 percent (BW) aggregates and 12 percent (BW) of the resin mixture, with the latter containing two percent (BW) catalyst.[1] This mixture has good workability and very little surface bleeding of the monomer during the curing operation. Shelf life of the mixture is limited to approximately 24 hours when stored at an ambient temperature of 21°C (70°F). Exposure to sunlight and storage at elevated temperatures (above 21°C) will shorten the shelf life accordingly. Shelf life can be extended by substituting mortar sand for kiln dust. Kiln dust contains chemicals which act as a promoter. A mixture of aggregates containing mortar sand instead of kiln dust was stored at SURC for more than one month with no apparent degradation or change in workability. However, substitution of mortar sand for kiln dust will result in a decrease in compression strength of PC. During field operation in bright sunlight and ambient temperature of 27°C (80°F) the storage life of the mixture with kiln dust is approximately one hour. The shelf life could be extended by covering the container of PC with light reflecting metalized paper or cloth or enclosing the material so that the evaporation of styrene is reduced.

Footnote:

[1] BW = 'by weight'

TABLE 1. SIEVE SIZE DISTRIBUTION OF AGGREGATES

Limestone	Sieve Size	Quantity Retained (Percent)
No. 1	1/2 inch	3.9
	1/4 inch	91.6
	1/8 inch	4.5
No. 1B(w)	1/4 inch	0.3
	1/8 inch	25.0
	No. 10	28.0
	No. 20	29.0
	No. 40	10.8
	No. 80	5.7
	200	1.0

TABLE 2. SIEVE SIZE DISTRIBUTION FOR AGGREGATE USED IN POLYMER CONCRETE

Sieve Size	Quantity Retained (Percent)
1/2 inch	1.00
1/4 inch	25.37
1/8 inch	16.85
No. 10	17.50
No. 20	18.13
No. 40	6.75
No. 80	3.56
No.100	6.00
No.200	2.83
No.250	1.20
<250	0.81

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SECTION III

FIELD TESTS

3.1 PREPARATION OF DAMAGED AREAS

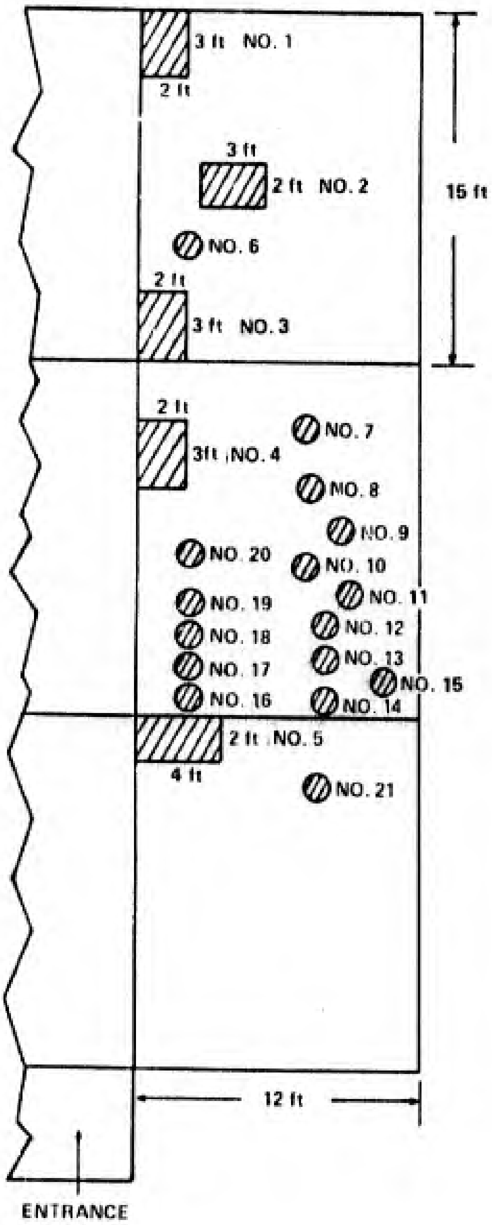
Preparation of damaged areas was started two weeks prior to the actual repair with PC. The area was designated by representatives of the NY State Air National Guard and consisted of an abandoned aircraft parking area constructed 40 years ago. The concrete is still in excellent condition. Figures 1 and 2 show the layout of the damaged areas. A jack hammer was utilized to prepare simulated damaged areas. Four large damaged areas were prepared with dimensions of 2 by 3 feet by 8 inches in depth (No. 1 through 4), one 2 by 4 feet (No. 5), and 16 small holes (No. 6 through 21) approximately 1 foot in diameter and 4 to 5 inches in depth. One large area (2 by 3 feet) was scaled in depth from 2 to 6 inches. Damaged area No. 5 (2 by 4 feet) was scaled in depth from 0 to 6 inches.

At the time of preparation of the damaged area, the area was dry and the base of the holes (i.e., base of the concrete) was dry. All damaged areas were cleaned with a broom and compressed air (Figure 4). During the week prior to the scheduled repair of damaged areas the weather condition worsened and several heavy rainstorms rendered the test site temporarily unusable. The repair of the damaged areas resumed after weather conditions improved. Repair of four large and four small damaged areas was completed.

3.2 MIXING OF MONOMER WITH CATALYST

Mixing of monomer with catalyst (Polylite 31-001 and benzoyl peroxide) was accomplished two days prior to the actual field test. The mixture was stored at room temperature (21°C).

Mixing of the chemical composition was performed by rotating a 5-gallon polyethelene container filled with 15.87 kilograms (35 pounds) of Polylite 31-001 and 320 grams (0.7 pounds) of benzoyl peroxide catalyst until thorough mixing had been achieved (approximately 5 minutes).



NO. 1	3 ft X 2 ft X 8 in
NO. 2	3 ft X 2 ft X 8 in
NO. 3	3 ft X 2 ft X 8 in
NO. 4	3 ft X 2 ft X 2 in TO 6 in SCALED
NO. 5	4 ft X 2 ft X 0 in TO 6 in SCALED
NO. 6 – NO. 21	≈ 1 ft DIAMETER, 4 in TO 5 in DEPTH

Figure 1. Layout of Damaged Area

Figure 2. General View of Test Area

Figure 3. Preparation of Damaged Area

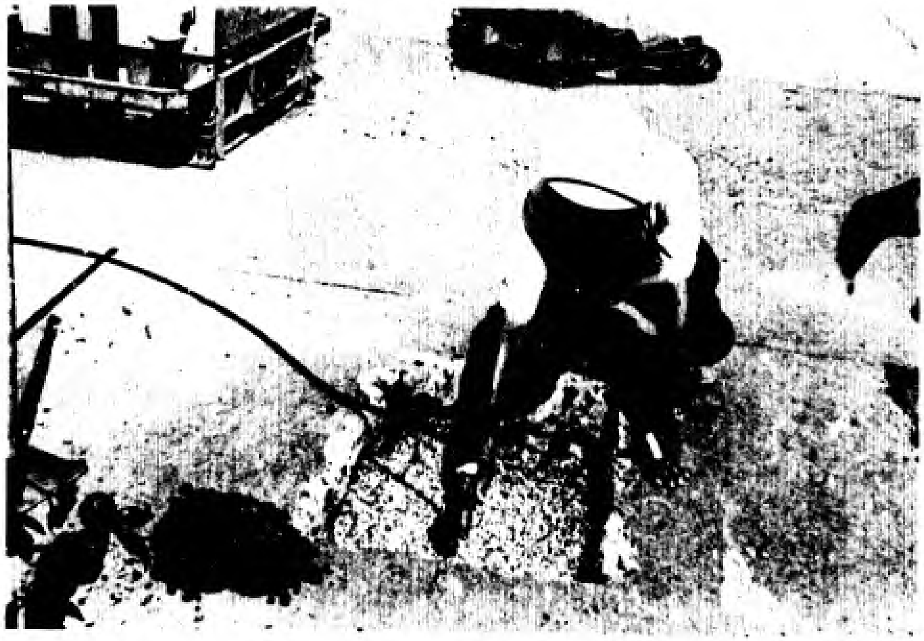


Figure 4. Compressed Air Cleaning

3.3 MIXING OF AGGREGATES

Aggregates were premixed at the SURC facilities prior to the field test. Measuring containers were marked to indicate the proper ratio of No. 1, 1B (w) and kiln dust. Proper sieve size distribution of the mixture required 4.3 kilograms (9.625 pounds) of aggregate No. 1, 9.525 kilograms (21 pounds) of aggregate No. 1B (w) and 1.984 kilograms (4.374 pounds) of kiln dust. This resulted in a total weight of 15.87 kilograms (35 pounds)--the maximum that the small electrically operated mixer which was used can handle. The mixed aggregates were packed in bags and stored.

3.4 MIXING OF PC COMPOSITION

The mixing of the catalyzed monomer and aggregates was performed at the test site prior to the repair of damaged areas (Figures 5 and 6). The contents of the bag-stored aggregate were placed in a 5-gallon metal pail. After adding 1.9 kilograms of catalyzed monomer (using marked containers), it was mixed for about 5 minutes in the same mixer previously used to premix the aggregate.

3.5 PLACEMENT OF PC COMPOSITION IN THE DAMAGED AREA

The premixed PC was emptied into the damaged area (Figure 7) and spread with a shovel. Afterwards the hole was completely filled and the mix was tamped with a hand tamper (Figure 8). The large damaged areas required several batches of PC and sectional tamping was utilized. PC in the half-filled holes was tamped thoroughly and then the hole was filled again with PC and tamped.

Thermocouples were inserted in the damaged areas during placement of the PC mixture to measure the temperature level during curing operation. Thermocouples were placed at a distance of 1 inch from the base of repair hole No. 2, under the reflecting screen in hole No. 3, and in the center in the hole No. 19. Prior to placement of PC into the damaged areas, the concrete surface area was painted with a mixture of catalyzed polymer diluted with styrene (10 percent BW). This step ensures good bonding of the PC to the Portland cement concrete

Figure 5. Preparation for Test

Figure 6. Mixing of PC

Figure 7. Placement of PC in Damaged Area

Figure 8. Tamping Operation

(PCC). In addition, the base of the large damaged areas was filled with the gravel mixed with catalyzed polymer (diluted with styrene; 10 percent BW) and mixed with aluminum powder. This step minimizes penetration of the microwave energy to the wet sand at the base of the damaged area and, therefore, prevents generation of steam which could have a detrimental effect on the polymerization and quality of the PC.

A thermocouple element inserted under the reflecting gravel registered a maximum temperature of 50°C during the curing operation. This is in contrast to the approximately 100°C measured in the PC itself.

The surface of the PC was screened and sprinkled with fine gravel (Figure 9). The gravel serves two purposes: (1) to increase the PC skid resistance and (2) to prevent the mixture from adhering to the applicator enclosure.

3.6 CURING OF THE PC

The polymerization of the PC was achieved by the thermal catalytic method. The microwave energy was applied to the PC by an applicator specially designed by SURC. A photograph of the microwave applicator placed over PC is shown in Figure 10. Uniformity of the energy distribution is imperative since the PC should be cured at the optimum temperature. An excessive increase in the temperature in the PC could result in vaporizing of the styrene content from the polyester mixture to the surface of the PC, making the PC porous and degrading the compression strength. The cure time of the PC with microwave energy depends largely on the mass of the material (PC) and applied microwave power level. The power level of the microwave energy in the SURC-developed system is controllable in two steps. In the high power mode of operation approximately 4 W/cm^2 (26 W/in^2) is applied to the PC under illumination. At the low power level, one half of the power is available (2 W/cm^2, 13 W/in^2).

The repair of the large damaged areas was accomplished by illuminating the PC with the microwave energy in the high power mode of operation. The small damaged area was cured using the low power mode of operation.

Figure 9. Screeding Operation

Figure 10. Placement of Microwave Power Generator over PC

Curing of the PC could be accomplished with either low or high power by the appropriate choice of curing time.

During repair of the three large damaged areas (full depth) a reflecting screen in the form of aluminum coated gravel was utilized. The reflecting paint was manufactured at SURC and consisted of a mixture of catalyzed polyester and aluminum powder. The main reason for utilizing such a reflecting screen was excessive moisture at the base of the damaged areas. The moisture (wet sand) at the base of the damaged area, when subjected to the microwave energy, could generate steam which could have a detrimental effect on the PC. Inhibition of polymerization could take place and escaping steam could degrade the compression strength of the PC (by increasing porosity). The reflecting screen minimizes penetration of microwave energy beyond the screen.

PC in damaged area No. 2 was cured at twice the optimum cure time. PC was illuminated with low power microwave energy (2 W/cm^2) for 15 minutes and then for an additional 9 minutes at high power (4 W/cm^2). The curing of PC in all four large damaged areas (No. 1 through 4) was accomplished by moving the applicator three times over the PC patch to ensure complete curing.

PC in small damaged areas did not require segmental curing. Attempts to cure PC in the wet damaged area were not successful. The bonding of PC to PCC was inferior and the two could be separated by hitting the sample with a hammer.

Damaged area No. 19 was damp prior to the placement of PC and required drying with the microwave energy (5 minutes at low power). Examination of the core sample shows good bonding of PC to PCC.

Table 3 shows the cure time and the level of microwave power required for curing of the PC in large damaged areas (1 through 4) and small damaged area No. 19.

One nondamaged area was subjected to the microwave energy for 20 minutes to determine detrimental effects, if any, on the Portland concrete cement (PCC). Figure 11 shows the examination of PC after curing operations.

TABLE 3. TEST DATA

CORE NUMBER	DA NUMBER	CURE TIME (MINUTES)	POWER PER		REMARKS
			cm^2	in^2	
1 PC 1 PCC 6 in 1 PCC 12 in	1	3 on-3 off-3 on 3 off-3 on	4W	26W	
2 PC 2 PCC 6 in 2 PCC 12 in	2	15 9	2W 4W	13W 26W	Cured at twice the optimum cure time. PC temperature: 80°C - 9 min 100°C - 15 min 120°C - 24 min
3 PC 3 PCC 6 in 3 PCC 12 in	3	15	2W	13W	DA filled with PC to 3/4 capacity on 7/30/75 - left overnight completed and cured on 7/31/75- not tamped as well as other DA. PC temperature: maximum 50°C (thermocouple inserted under reflecting gravel)
4 PC/PCC	4	9	2W	13W	DA slanted from 2 to 6 in
19 PC/PCC	19	5	2W	13W	DA approximately 12 inch diameter. 4- to 5-inch depth. PC temperature: 70°C - 3 min 80°C - 5 min
Core No. X PCC	-	15	4W	26W	PCC heated by microwave to approximately 120°C

PC = Polymer Concrete
PCC = Portland Cement Concrete
DA = Damaged Area

Figure 11. Examination of PC after Curing

3.7 CLEANING OF TOOLS

Cleaning of tools after completion of the repair of the damaged areas was accomplished by wiping off the small tools such as rakes and shovels with a cloth moistened with methylene chloride. The metal pail from the mixer was charged with dry aggregate and after the addition of a small amount of styrene was rotated until the surfaces were clean.

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SECTION IV

SAMPLING AND TESTING

4.1 CORING

Core samples were taken from each of four large repaired areas (No. 1, 2, 3, and 4) and a small damaged area (No. 19). One core sample was also taken from PCC previously subjected to microwave energy for 20 minutes until the temperature increased to approximately 120°C (248°F). Additional core samples were taken from the area adjacent to the repaired areas--one 6 inches and another 12 inches from the PC. Photographs of the core samples are shown in Figures 12 and 13. Cores extended down to the base of the PCC and PC. The PC core samples taken from full depth damaged areas are longer by approximately 1-1/2 inches than PCC core samples.

One set of 14 cores was sent to the Air Force Civil Engineering Center, Tyndall AFB, Florida for tests in their laboratories. The other set was used in laboratory testing at the SURC and Syracuse University test facilities.

4.2 COMPRESSION TEST

Compression tests were performed at the Syracuse University test facilities. Due to a tight schedule at the SU test facilities, the soaking of core samples for 40 hours (as recommended in ASTM-14 C42) was omitted and the data shown in Table 4 are taken on dry core samples. Core samples were cut with a masonry diamond tipped saw to the length of 4 inches to allow SURC researchers to perform additional tests at SURC on remaining portions of the core samples. The diameter of the core samples was 4.2 inches, resulting in an L to D ratio of ≃ 1, instead of 2 as recommended in ASTM-39 (ASTM-14 C-42). A correction factor of 0.91 was included in the results due to this L to D ratio.

Table 4 presents the data collected during compression strength tests.

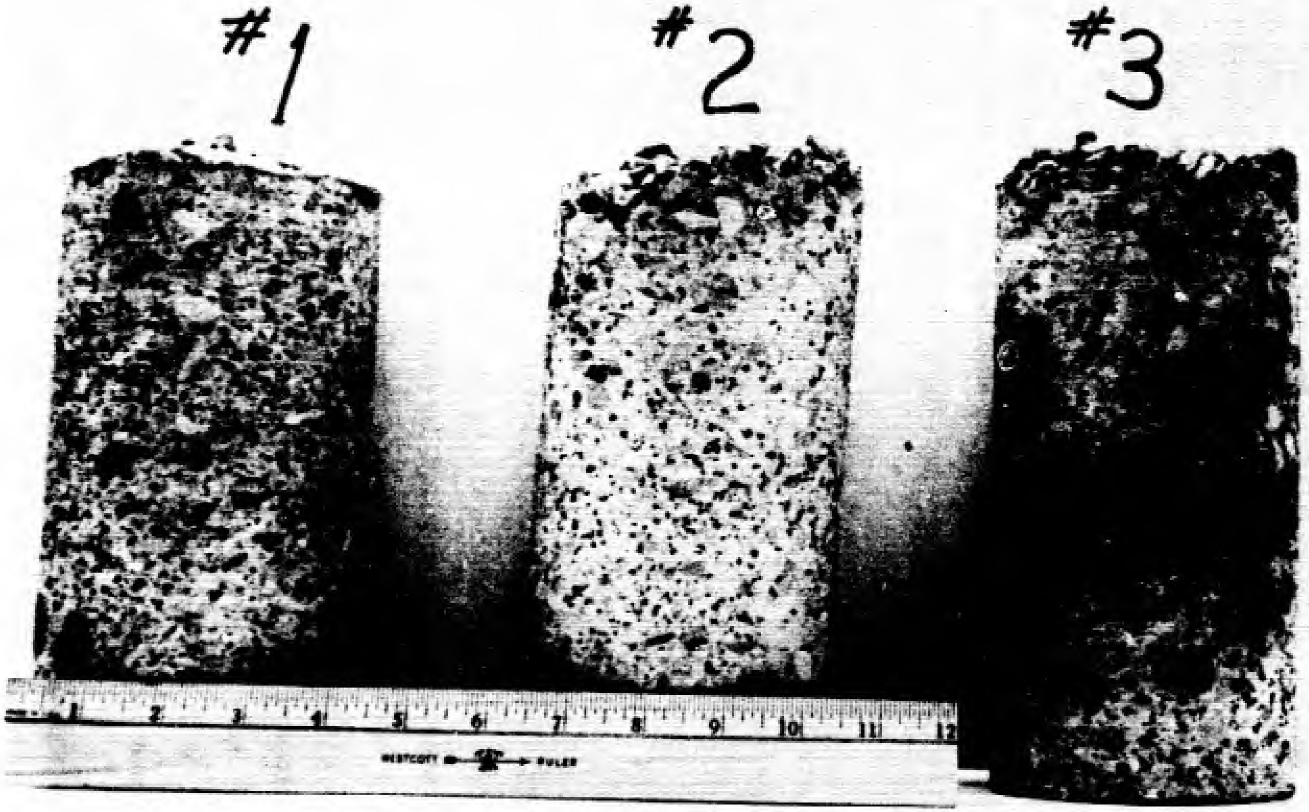


Figure 12. Core Samples (1 through 3) No. 1 PC, No. 2 PC and No. 3 PC

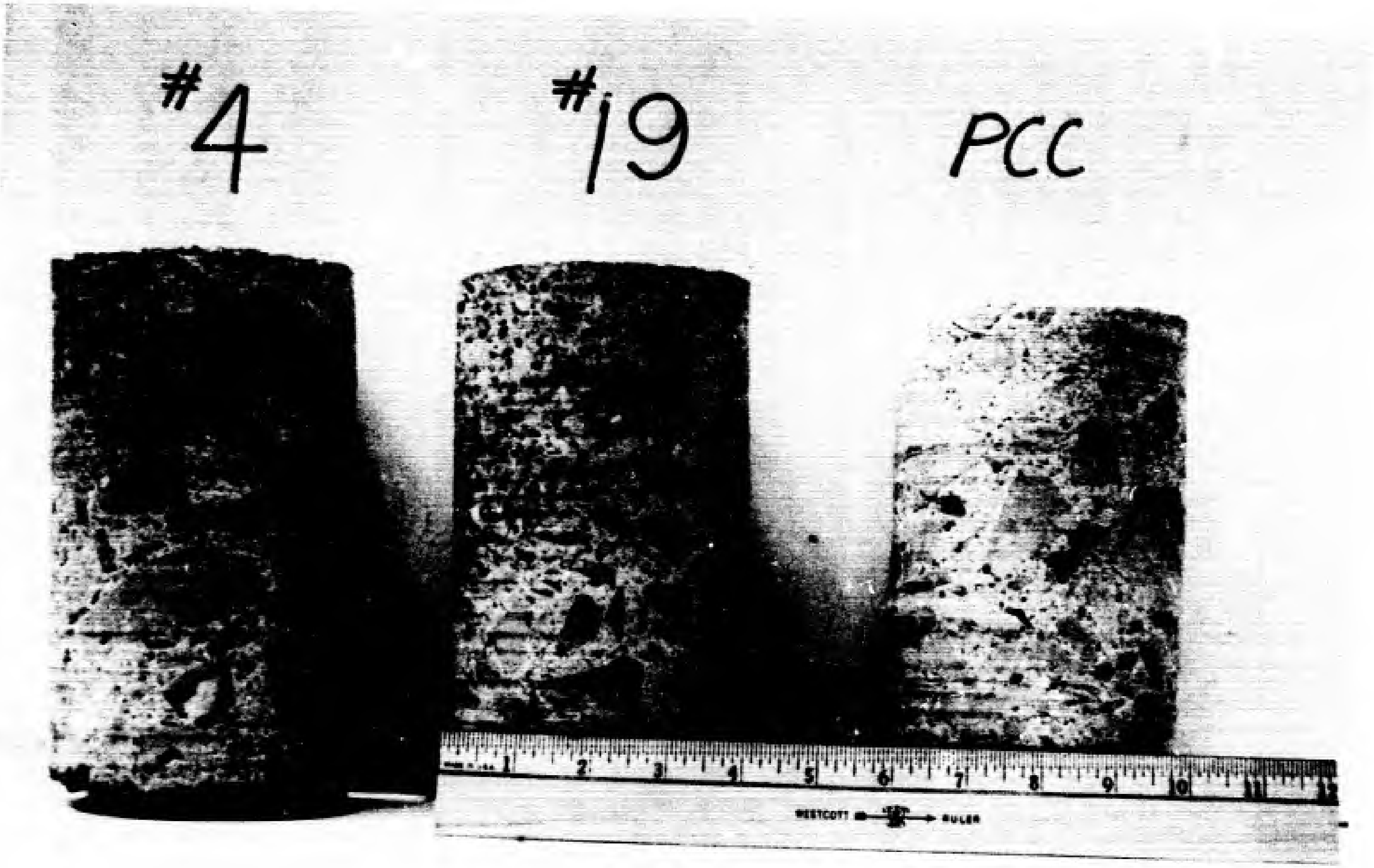


Figure 13. Core Samples (No. 4 PC/PCC, No. 19 PC/PCC and PCC)

TABLE 4. COMPRESSION TEST DATA

SPECIMEN	COMPRESSION FORCE IN POUNDS	COMPRESSION IN PSI	COMPRESSION IN PSI (Corrected)
PC-1	110,000	7,942	7,227
PCC-1(6)	57,500	4,151	3,777
PCC-1(12)	64,500	4,657	4,237
PC-2	81,500	5,884	5,354
PCC-2(6)	65,500	4,729	4,303
PCC-2(12)	64,500	4,651	4,237
PC-3	55,000	3,971	3,613
PCC-3(6)	61,000	4,404	4,007
PCC-3(12)	60,500	4,368	3,975
PC/PCC-4	54,500	3,435	3,580
PCC-4(6)	60,500	4,368	3,975
PCC-4(12)	57,500	4,151	3,777
PC/PCC-19	81,000	5,848	5,322

Note: (6) and (12) in PCC specimen denotes distance in inches from PC in the damaged area.

4.3 SPECIFIC GRAVITY, ABSORPTION AND VOIDS IN PC (ASTM-C642-T)

These tests were conducted at the SURC laboratories. The balance used during this test was a Mettler Instrument Co. Electronic Scale, Model No. P1000. Core samples were dried in an oven at a temperature of 105°C for 48 hours, weighed, and immersed in water (21°C) for 54 hours. Samples were weighed at time intervals of 24 hours and 54 hours. The specimens were surface dried (towel dried) before weighing.

Saturated weight was determined by boiling the specimen for 5 hours, cooling to a temperature of 21°C, surface drying, and weighing. The immersed weight of the core samples was recorded while the samples were suspended in water. Table 5 presents data collected during the test and computed void volume percent, bulk specific gravity, and water absorption.

4.4 GASOLINE AND JP-4 FUEL TEST

Core samples were dried in the oven for 48 hours, cooled, weighed, and immersed in gasoline and aviation fuel (JP-4) for 7 days. After 7 days immersion in the JP-4 and gasoline, samples were air dried for 48 hours and then weighed. Table 6 shows the data collected during the test and illustrates the stability of PC to these materials. No weight loss was detectable.

4.5 FLAME TEST

Part of one core sample was subjected to propane flame for 3 minutes. The PC burned only when the flame was applied to it indicating that the material is self extinguishing (that is, it does not support combustion).

TABLE 5. VOID VOLUME PERCENT, BULK SPECIFIC GRAVITY AND WATER ABSORPTION

SPECIMEN	OVEN DRY WEIGHT (g)		SATURATED WEIGHT AFTER IMMERSION (g)		SATURATED WEIGHT AFTER IMMERSION AND BOILING (g)	IMMERSED WEIGHT (g)	ABSORPTION AFTER IMMERSION %	ABSORPTION AFTER IMMERSION AND BOILING %	BULK SPECIFIC GRAVITY (dry) g1	BULK SPECIFIC GRAVITY AFTER IMMERSION	BULK SPECIFIC GRAVITY AFTER IMMERSION AND BOILING	APPARENT SPECIFIC GRAVITY g2	VOID VOLUME % $\frac{g2-g1}{g2}$
	24 hrs	48 hrs	48 hrs	54 hrs	5 hrs								
PC-1	467.4	467.3	468.0	468.0	473.7	271.3	0.1497	1.369	2.3365	2.335	2.363	2.408	2.969
PC-2	462.6	462.5	463.1	463.1	469.3	266.9	0.1297	1.470	2.285	2.288	2.318	2.364	3.34
PC-3	444.0	443.8	445.9	445.9	454.7	256.[illegible]	0.4731	2.456	2.235	2.246	2.290	2.3656	5.520

TABLE 6. GASOLINE AND JET FUEL (JP-4) TEST

	DRY WEIGHT (g)	WEIGHT AFTER SOAKING IN GASOLINE	WEIGHT LOSS (%)	DRY WEIGHT	WEIGHT AFTER SOAKING IN JP-4	WEIGHT LOSS (%)
PC-1	459.1	459.1	0	451.9	451.9	0
PC-2	506.8	506.8	0	332.1	332.2	0
PC-3	420.4	420.4	0	404.2	404.2	0

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The work to date conducted in the area of polymerization of polymer concrete with microwave energy (thermal catalytic method) has indicated that this approach has good possibilities for rapid runway repair. The danger of premature polymerization which exists during the application of PC with the promoter-catalytic method is eliminated with the thermal catalytic method of polymerization. By utilizing microwave energy instead of other forms of heat (infrared, etc.), all levels of the material are heated simultaneously, with the result that the polymer concrete is uniformly cured and of high quality.

For this contract, various size holes in damaged concrete were filled and core samples taken. Each core sample was tested in the laboratory to ASTM-39 for failure analysis. As can be seen from data collected during these compressive strength tests, the compressive strength of PC surpasses PCC by almost 2:1.

The importance and need of proper tamping of PC prior to the application of microwave energy was demonstrated during the repair of damaged area No. 3. The PC in this hole was not properly tamped with the consequence that the material had low compressive strength.

The presence of moisture on the surface of the PCC prevents good bonding of PC to PCC and, therefore, the damaged area should be dried prior to the placement of PC. This can be accomplished by the application of microwave energy.

The repair of smaller damaged areas was accomplished more efficiently than large damaged areas. This was mainly due to the lack of larger construction equipment such as concrete mixers and mechanized tampers. Given this equipment, larger damaged areas would not pose a problem.

Both full depth and partial depth holes were filled with good results in both types of patching. SURC has developed a good technique (which uses a powdered metal paint) for confining the microwave heating to the PC material in the repaired area.

Critical timing and exposure of the PC material to the microwave heating is not a problem. Over curing has been accomplished and, as long as violent boiling of the materials is avoided, there are no problems and strength is maintained.

Since some of the holes repaired were large enough to require overlapping of the microwave applicator, problems could be expected at the juncture of two microwave energy applications. No effects of this kind have been noted, and all core samples obtained have shown good results in compressive strength tests.

The hardened PC was subjected to flame tests which indicated that this material will burn only when exposed to an open flame and will not support combustion. Also, no adverse effects on the PC have been produced as a result of soaking in JP-4 and gasoline for an extended time period.

During the course of this project, it became evident that the mixing of polymer concrete materials on-site appears to be the most sensible approach. If the materials are pre-mixed, there is a certain amount of settling out which necessitates mixing before the material can be used. Thus, since additional mixing is required, it would seem best to do this operation only once. Because the polymer material has a relatively short shelf life (one year), it would be more economical to replace only the liquid chemicals involved rather than the entire concrete material including the aggregate. For this reason, SURC recommends that the aggregate be stockpiled under waterproof plastic sheets and the polymer be stored in a place which is cool, dark, and not far from where it is expected to be used.

5.2 RECOMMENDATIONS

Due to the encouraging positive results of these initial tests, several areas of additional effort seem warranted. SURC has not had an efficient method of mixing and tamping the PC for this project, but it is easy to see where this operation could be improved upon. This would allow runways to be repaired as fast as the microwave equipment is put in place plus curing time. Presuming that the polymer concrete material is sufficiently strong, bonds well, and handling and storage characteristics are adequate, additional research efforts should be expended on determining a more optimum and cost-effective design for the microwave application to the runway surface. This should be accomplished in close cooperation with potential users.

Although the microwave curing of PC is much more rapid and controllable than other approaches, the time for cure is still on the order of ten minutes. Additional experimentation with other chemicals and materials should result in cure times that are further reduced. If the total repair process is limited by the cure time, this may be an important factor from both the time and equipment investment standpoint. Practical trade offs between power, curing time, and material have to be established.

An area that is certain to pay off is the striving to improve the characteristics of the polymer such that the threshold of exothermic reaction may be reduced, for instance, to 60°C rather than 80°C which it presently requires. This will result in several advantages: the microwave energy required for cure will be less and the material temperatures can be less. This is desirable in most instances because water or moisture, which are always present, convert to steam when high temperatures are required. Also, cure times will be significantly reduced since the exothermic threshold will be reached much sooner. Again, this material development should be accomplished in close cooperation and in conjunction with microwave experimentation in order to ensure that the excellent characteristics of the present material are not compromised.

A study and tests of storage life characteristics of the polymer-catalyst-aggregate mixes are also desirable efforts at this time. UV inhibitors and metal chelating agents could play an important role.

Further experimentation should be performed with regard to filling damaged areas of the concrete. The program that SURC undertook initially involved filling the full depth (8 inches) of damaged area which worked quite well. However, if larger areas and deeper areas might be considered, the type of experiments that should be run would be for back-filling the larger excavations or holes with regular gravel or other fill material, tamping firmly with proper equipment, and then determining if a thin (2- to 3-inch layer) PC top patch would hold up even on a temporary basis. It may be necessary during time of war to expedite the repair of runway surfaces in a manner which would not be recommended for long range goals. The question would be whether such a thin layer would be able to withstand normal wear and tear of aircraft traffic without fracturing or cracking and crumbling due to its thinness. In experimenting with larger areas, such as 5 feet or larger on a side, experience and knowledge could be gained which might lead to possible future equipment design requirements.

Additional experiments regarding the bonding of the polymer concrete to the Portland cement should be performed in order to find out the level of shear forces that the patch material can withstand. Tension or cantilever type tests should be adequate for determining this type of characteristic. Fixtures would undoubtedly have to be fabricated in order to perform these kinds of tests. New core samples would be necessary to test a smooth surface bond between PC and PCC in contrast to the jagged surface bond that resulted from jack hammered surfaces, such as made in the original effort.

Some experimentation should be devoted to the examination of microwave curing of materials other than polyester in order to patch holes with greater quantities of moisture present. For instance, FURAN[2] or other type chemicals (which can be mixed with water) may be used in these experiments.

Footnote:

[2] Registered trademark; manufactured by Quaker Oats Company.

APPENDIX A

SUMMARY OF RELEVANT TECHNOLOGY

A.1 INTRODUCTION

The work heretofore discussed covers two areas of technology that may not be familiar to the user of this report. These areas are polymer chemistry and microwave power technology. Because of the anticipated lack of familiarity with these areas, this appendix presents a brief introduction of pertinent technological background to make the entire report more meaningful. The background discussion to follow is not designed to give a full background in the respective areas and should be supplemented with additional sources to fully understand why certain approaches were used by the SURC research team.

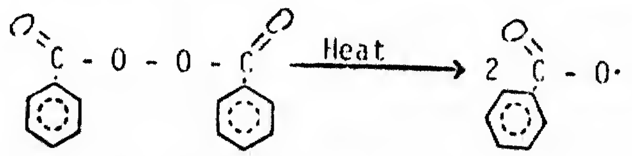
A.2 POLYMER CHEMISTRY

The background technology for the following sections will be discussed relative to the polymerization process and types of materials.

The chemical process of polymerizaion is the basis for the chemically oriented portion of the work conducted during this contract and related work for highway-oriented agencies. The desired polymerization reaction occurs when a monomer molecule is provided with the proper conditions to react with other monomers. These monomers can be of a single chemical type or of several types. An analogy for the polymerization process is a large series of separate toy train cars sitting on a track. Since none are moving they are unable to couple with one another. Action starts when the engine hits one car and couples to it, which then goes on down the track connecting all the cars together. In the analogy, the separate cars are the monomers, the connected chain of cars is the polymer, and the proper conditions are armed couplers and a moving engine to provide the driving force.

In the chemical case the reaction uses a free radical or ionic molecule to push the reaction. The work of this program is not believed to involve ionic polymerization, therefore, no further mention will be made of this aspect. The method where the free radical is formed usually involves the decomposition of a peroxide catalyst which is typically divided into two free radicals. The free radical is a molecule which has an unpaired electron, the inherent properties of which make the molecule very reactive. These free radicals react with a monomer molecule forming a chemical bond and transferring the free radical property to the monomer end of the newly formed molecule. This process continues until a chain terminating step occurs. The polymerization reaction can be presented in an outline form. For the purpose of discussion, benzoyl peroxide, a peroxide catalyst, and an unspecified monomer "M", will be used. The complete reaction is as follows:

1. The highly conjugated oxygen bond in the peroxide molecule will break and form two free radicals. The reaction can be represented as:



2. The unstable free radical formed will decompose as follows.

3. The free radical now formed will react with a molecule of monomers which we will call "M".

4. This process continues to add more monomer molecules:

5. This process will continue until a reaction occurs that stops the process. This type of reaction is called a chain terminating reaction and in one way or another reacts with the free radical to deactivate it.

The primary type of chemical system found effective for rapid pavement repair is a styrenated polyester. As the name polyester implies, this material is already a polymer. The polyesters of interest are unsaturated, or in other words, have available bonding sites which allow a monomer to cross bond and bridge two polyester molecules together to form a unified larger molecule. On the large scale, this reaction produces a unified solid mass. The crossbonding monomer in most cases is styrene, but methylmethacrylate (MMA) and others can be used with favorable results. The specific chemical system used in this program will be discussed and comparisons with the experimental results previously obtained in the laboratory will be made. These results are pertinent to the applicability of microwave energy for expedient runway repair.

The primary chemical property of the polymerization reaction that the SURC system utilizes is the energy of activation. Polymerization, by a free radical mechanism, can proceed via two primary methods; one is the promoter catalyst and the second is the thermal catalytic method. In either method an energy boundary must be overcome to start the chain reaction which, for most cases, is exothermic and self propagating. With the promoter catalyst method the material will start to polymerize as soon as all the components are added. This is true as long as the ambient temperature is high enough to allow the reaction to proceed.

With the thermal catalytic method, reference to Figure A-1 is helpful. This figure gives the typical energy requirements of a chemical reaction, which could be a polymerization reaction. When energy is applied, the energy of activation is reached and as long as a sufficiently high energy state is maintained, the reaction continues. In the work discussed in this report, the energy of activation is provided by microwave power.

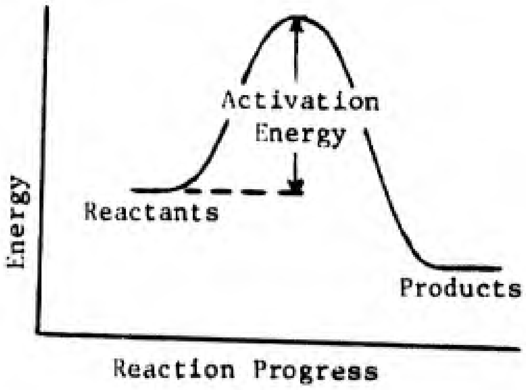


Figure A-1. Chemical Activation Energy

The advantages of the thermal catalytic method are that curing can be obtained when wanted and, for the applications under discussion, the work crew does not have to do extensive on-site mixing of the component chemicals. As the SURC work has shown, a three-day or longer pot life of the complete system is feasible. The reason for choosing microwaves is that the time consuming process of thermal conduction is not a factor, because the entire bulk is heated simultaneously.

A.3 MICROWAVE TECHNOLOGY

The second area of technology pertinent to the contents of this report is the area of electrical engineering concerned with microwave power. The two component areas of technology that will be discussed are the properties of dielectric materials and the propagation of electromagnetic waves. The method of producing microwave power will not be discussed in that it has no bearing on this report and commercially available microwave components were used at all times.

Before the above topics are discussed, the question of what microwaves are should be answered. The term microwaves defines a range of electromagnetic spectrum which lies between radio waves and infrared light. The primary frequency that is of interest in this report is 2,450 Megahertz (MHz), or 2.45 billion cycles per second, with several other frequencies being allocated by the FCC for power applications. These other allocated frequencies have little applicability for the type of repair covered by this report and, therefore, will receive no further mention. The wavelength of the 2,450 MHz microwaves is about 4.8 inches which is the quantum mechanically allowed to pass through an electrically non-conductive material. The important reaction, for our purposes, occurs when microwaves pass through a material containing molecules which have a dipole moment. The effect of this action is a reorientation of that dipole to align with the field established by the microwave energy. With the 2,450 MHz frequency the change in orientation occurs 2.45 billion times per second, creating a considerable molecular friction and a consequent heat rise.

A.3.1 Properties of Dielectric Materials

Generation of heat in the material subjected to illumination with microwave energy is only possible when the material is of a type which absorbs such energy. Material which reflects the major portion of incident energy or is transparent (i.e., permits energy to pass through without appreciable loss) is not suitable for microwave heating.

Absorption of the energy is dependent on a property of the material which can be expressed in terms of complex relative permeability, $\mu = \mu' - j\mu''$, with the loss tangent, $\delta = \mu''/\mu'$, and the complex relative permittivity, $\varepsilon = \varepsilon' - j\varepsilon''$, with loss tangent, $\varepsilon = \varepsilon''/\varepsilon'$. Both quantities are a measure of the polarization which the material undergoes under an applied electric field. In the above expressions j is the complex operator $\sqrt{-1}$.

Since the materials under consideration in this program are of a dielectric type (non-conductive), only the permittivity (dielectric constant) and dielectric loss tangent or dissipation factor are of interest.

The molecules of dielectric materials can be classified either as polar or non-polar types. Polar molecules have a dipole moment even in the absence of an electric field whereas non-polar molecules require an electric field to produce a dipole moment. A pair of electric charges, equal in magnitude but opposite in sign, being very close together on the same molecule, constitute an electric dipole (dipole molecule). The product of the two charges by the distance between them is called a dipole moment.

At low frequencies, the loss tangent (dissipation factor or amount of microwave capture) of the dielectric material diminishes and only the dielectric constant is measurable (static field measurement). An increase in the frequency of the applied electric field prevents the dipolar molecules from attaining the necessary speed to maintain equilibrium with the electric field. The loss tangent, therefore, increases.

The energy necessary to force alignment of the dipolar molecules with the applied field is dissipated in the form of heat. Penetration by the microwave energy through an absorbing material is not uniform, with the energy availability for heating being diminished as it progresses through the material, resulting in a non-uniform heating of the material. This non-uniform heating is manifested with the larger portion of the energy being dissipated closer to the surface.

The penetration of energy through the dielectric media is not only dependent on the dielectric properties of the material but is also frequency dependent. The depth of penetration increases with a decrease in frequency.

From the above discussion, it is evident that the judicious selection of dielectric materials and frequency of the applied field could optimize the heating of the material. However, some limitations are imposed on the selection of material for pavement repair. Materials exhibiting good dielectric properties from the standpoint of rapid heating (when subjected to the microwave energy illumination) do not necessarily possess the proper physical properties required for highway or runway repairs.

Frequency selection is dictated by FCC regulations, with several frequencies allocated for heating uses. The frequencies of 915 and 2,450 MHz were initially considered for pavement repair because of their availability and high potential for success. In subsequent research at SURC the 2,450 frequency was found more applicable, primarily because of the associated depth of power penetration.

APPENDIX B

A DESCRIPTION OF THE MICROWAVE ROAD/RUNWAY PATCH SYSTEM

B.1 ELECTRICAL DESIGN

Figure B-1 is a simplified block diagram of the complete microwave power generating system, including the control panel, remote control, and applicator.

The system's primary power is supplied by a 50-kW, 208-240 Vac generator.

Eight individual microwave power units supply 2.5 kW each of microwave power at a frequency of 2450 ± 50 MHz. Control units provide all necessary controls for operation of the system. Any or all of the 2.5 kW units can be readily selected, thus enabling the operator to select the proper segment of the applicator to physically match the area to be cured.

The outputs of each individual unit are fed via circulators and flexible waveguides to the applicator. A circulator is provided to protect the magnetrons from possible excessive microwave energy reflected from the media under illumination. A high reflection condition could be encountered during road, runway, or bridge deck patch curing where highly reflective materials such as metal rods are imbedded in the pavement.

Although the applicator is an inherent part of the microwave power generator system, flexible waveguides are provided to feed the energy to the applicator to minimize the possibility of damaging waveguide flanges and isolate vibration between applicators and magnetrons. The applicator is of a slotted waveguide type which eliminates mechanical stirrers. Tests indicate that this type of applicator is best suited for the kind of material heating under consideration.

A remote control is provided to switch the system from the standby to the radiate mode of operation. This is one of the many safety features

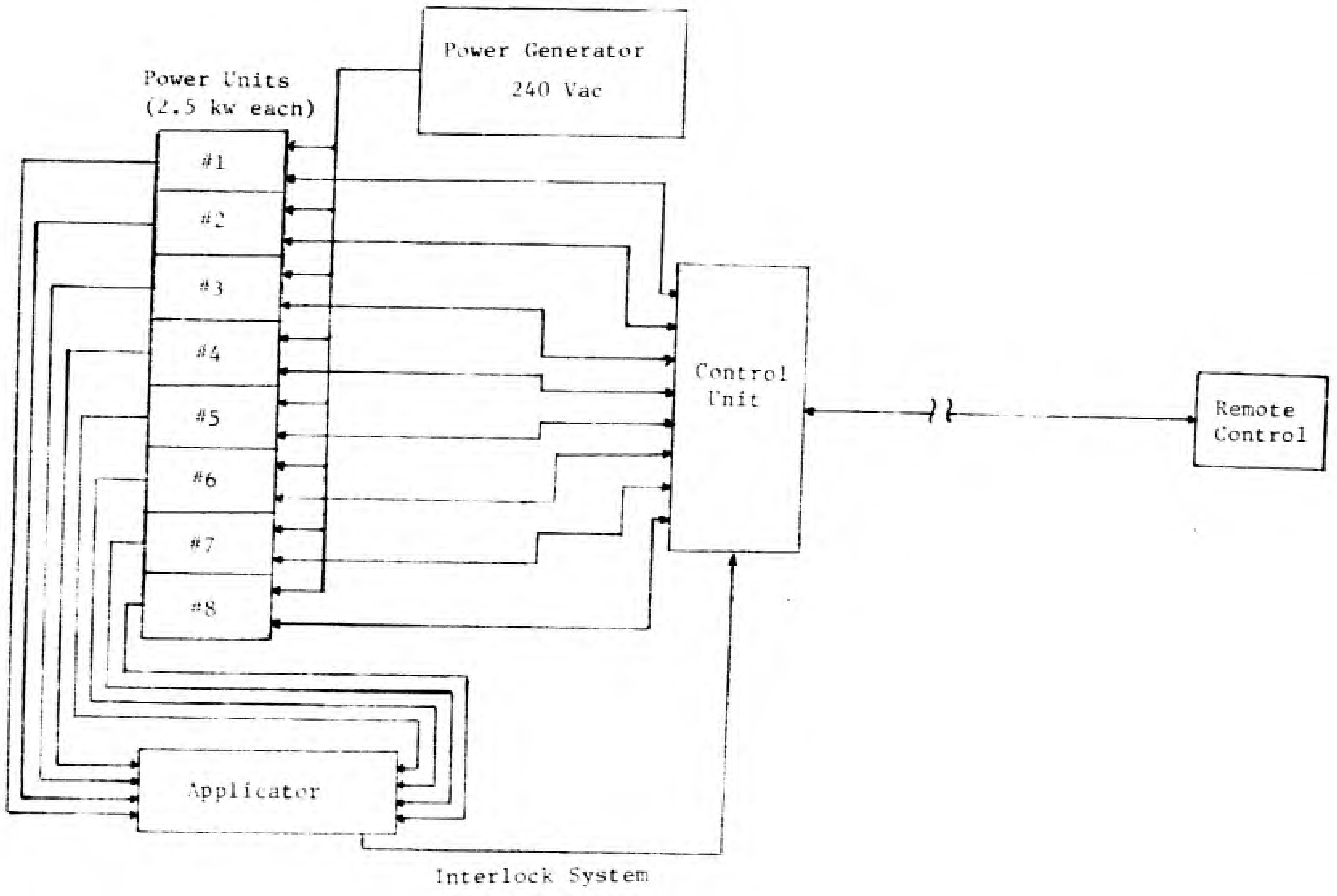


Figure B-1. Simplified Block Diagram of 20 kW Microwave Power Generator incorporated in the system. It is felt that regardless of how reliable the system is in the area of microwave energy leakage, the safest procedure is to keep the operator at a safe distance from the microwave power system when radiating.

Several other safety features are provided to protect operating personnel from possible exposure to excessive microwave energy.

The individual units have interlocks built into all removable enclosure panels. (Removable panels are necessary for servicing of the unit.) Removal of the panels or any tampering with the interlocks will cause an automatic shut-off of the power unit.

The applicator has two interlocks along the periphery of its enclosure. These are connected in series so that all must be closed to enable the system to radiate. This procedure assures close proximity of the applicator to the pavement, thus preventing excessive leakage of the microwave energy to surrounding areas.

In addition to the automatic system shut-off, the system has a flashing warning light mounted on top of the unit which is illuminated when the system is switched into the radiate mode.

With all these safety precautions, it is thus certain that the operating personnel will not be subjected to any harmful radiation from the microwave power generating unit and applicator under prescribed operating procedures.

Performance of the system has been thoroughly tested. System performance in the areas of power output, uniform energy distribution, and ease of operation has been found to be very good. Versatility of the system is excellent in terms of placement on the designated patch areas.

Leakage of microwave energy beyond the periphery of the system is well below established levels. (HEW Rules and Regulations stipulate that power must be below 1 mW/cm^2 at a distance of 5 cm from the enclosure of the system.) The leakage at any point along the periphery of the enclosure of the system was measured at a maximum of 0.5 mW/cm^2 at a distance of 5 cm. The aforementioned safety features such as interlocks (panel and applicator) and remote switching of the system were tested and found to be reliable.

B.2 MECHANICAL DESIGN

Operation and tests of the complete system showed that all basic design criteria have been met.

Figures B-2 and B-3 depict the highway/runway patch system.

The modification of the State of Illinois' International 12 T dump truck turned out well. The frame behind the cab was lengthened 5 feet, which meant that a new drive shaft, brake tubing, and electrical wiring to rear were required. A split steel bed was designed, built, and mounted to the truck frame. A new HIAB hydraulic loader with outboard stabilizing jacks was mounted between the bed sections. To make the truck roadworthy, all front spring shackles were replaced and new brake cylinders installed.

Vibration isolation of the sensitive components of the microwave generator from both the diesel generator and the truck vibrations and shock is satisfactory. There was some concern that the HIAB boom might amplify the diesel-generator vibration; however, the energy being transmitted through the vibration isolation mountings under the diesel generator is not enough to cause vibration of the boom.

Positioning and storage of the microwave generator is accomplished with the HIAB and its four easily operated controls [two vertical, one horizontal (stinger), and one boom rotation]. The stowage base for the microwave generator is equipped with wedge-like guides (on the front, rear, and each side) to facilitate quick placement. Although the original concept of rotational positioning of the microwave generator was to be by remote hydraulic control (the system was originally so equipped), it was found that manual rotational positioning was easier and quicker.

The routing and attachment of four No. 2 welding cables and two 1/2 inch (id) heavy-duty hoses for water cooling of the microwave generator over and

Figure L-2. Microwave Road/Runway Patch System

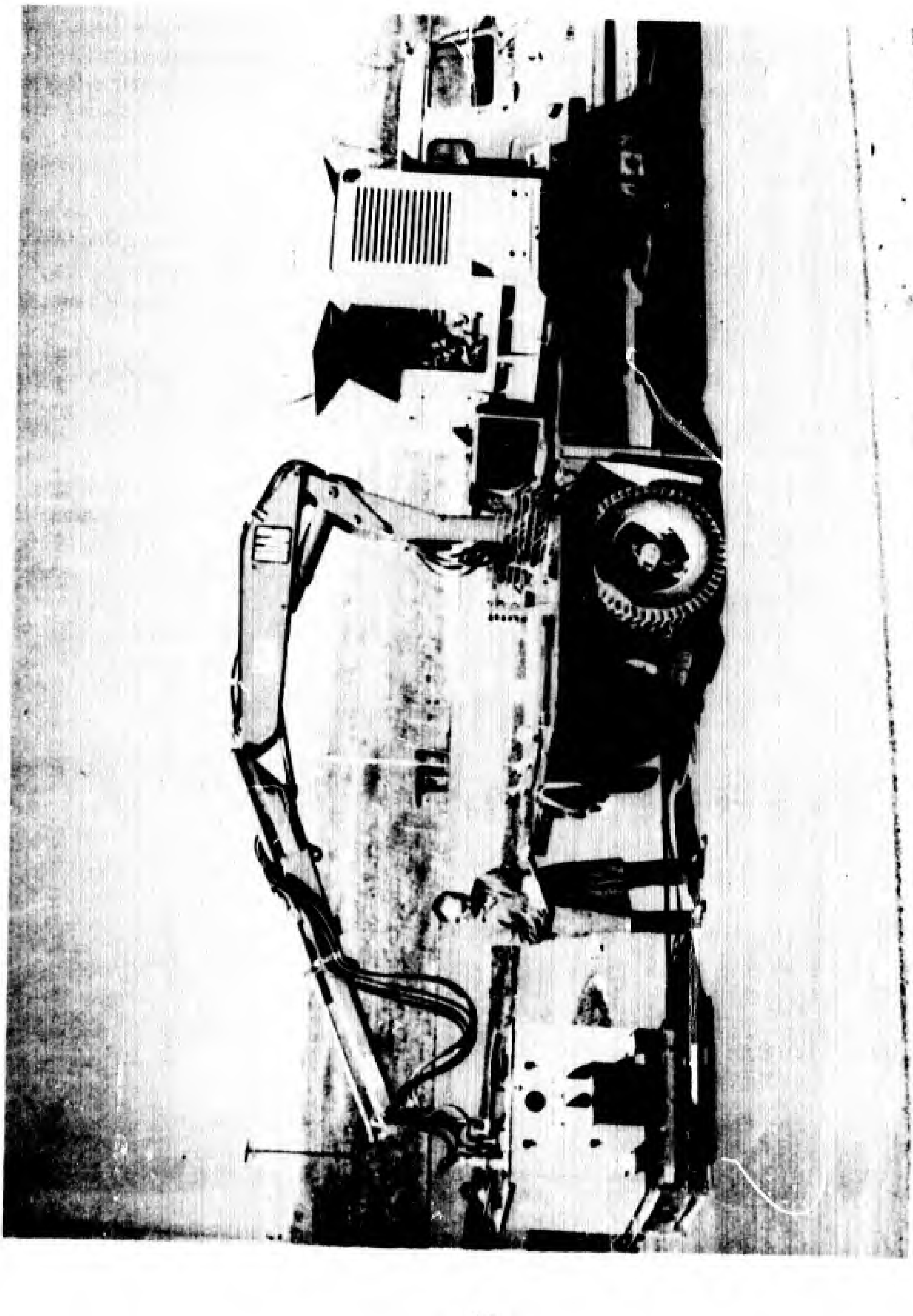


Figure B-3. Microwave Road/Runway Patch System in Operation through joints of the HIAB has functioned well. Quick-release shut-off water couplings make connection to the microwave generator cooling system convenient.

The water-air heat exchanger designed and built to supply cooling water to the eight magnetrons in the microwave generator and associated components delivers approximately 8 gpm at 30 psi. During the tests, the heat exchanger provided sufficient cooling to maintain megnetrons well within their temperature limits on a 90°F day during sustained operation.

Four additional 100 cfm muffin fans remove air from the microwave generator, and four other similar fans stir and mix air around the components of each tray in the generator. A 300 cfm blower unit removes air from the area under the applicator. This air is drawn over the surface of the patch and from the magnetron's launcher through the waveguide and slotted applicators. This flow tends to keep the applicator and waveguide clean while removing steam and vapor from the patch area.

A four-pole, heavy-duty industrial connector provides quick connection and release for electrical power. Within the microwave generator, quick-disconnect, shut-off water couplings and plug-in electrical power provide easy removal of the magnetron, power supply, and control trays for servicing.

Rugged, tear-resistant, neoprene-coated nylon covers, secured by rubber rope and hooks, are used over both the diesel generator and the microwave generator during travel or while standing when equipment is not in use.

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APPENDIX C

NOTES ON SYSTEM OPERATION

C.1 FORMULATION OF PC (POLYMER CONCRETE)

C.1.1 Polyester (Reichold Chemical Company Polylite 31-001)

C.1.2 Benzoyl Peroxide Catalyst or Methyl Ethyl Ketone Peroxide Catalyst

C.2 INSTRUCTION FOR MIXING (USING BLADE MIXER)

C.2.1 Weigh into tarred container:

a. Resin system - 12 percent BW of aggregate
b. Catalyst - 2 percent BW of polyester
c. Charge mixer container with pre-weighed aggregate
d. Stir thoroughly to attain good mix
e. Pour catalyzed polyester and mix for about 5 minutes

C.3 EQUIPMENT RECOMMENDED FOR PC WORK

a. Jack hammer
b. Air compressor
c. Mixer (Paddle or blade)
d. Paint brushes
e. Broom
f. Shovel
g. Weighing scale (100-pound)
h. Tamper-preferably motorized
i. Screeding device (2 by 4 board or equivalent)
j. Microwave power source with lifting mechanism
k. Primary power generator

C.4 SUPPLIES NECESSARY FOR PC REPAIR WORK

a. Polymer resin (Reichold Chemical Company Polylite 31-001)
b. Catalyst (Benzoyl Peroxide or Methyl Ethyl Ketone Peroxide)

c. Cleaning solvent (Methylene chloride)

d. Aggregate (See Table 2)

e. Gloves, cleaning rags, etc.

f. Containers for mixing and measuring

g. Fine gravel to cover PC

C.5 SAFETY PRECAUTIONS

(Materials utilized for PC polymerized by thermal catalytic method are not as hazardous as materials used in promoter-catalytic method. Nevertheless care should be exercised in handling the polymer, catalyst, and cleaning fluids.)

a. Polyester is flammable. Smoking should be prohibited in test area and good ventilation should be maintained.

b. Polyester and catalyst could irritate skin, therefore should be handled with care. Hands should be washed using methylene chloride. Acetone is acceptable but this chemical is flammable and should be handled with caution.

c. Microwave power system should not be tampered with. No attempt should be made to bypass safety features built into the system.