Bonded Resurfacing and Repairs of Concrete Pavement

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● FOR SEVERAL YEARS the Research and Development Division of the Portland Cement Association has investigated methods and materials for bonding relatively thin layers of concrete to old pavements or floors. The latoratory tests were designed to evaluate such factors as surface cleanliness; smooth and roughened surfaces; damp and dry surfaces; cement-sand mortars and neat cement grouts for bonding courses; concrete resurfacing mix designs; and methods of placing the resurfacing concrete, including surface and internal vibration, mechanical float compaction and pneumatic pressure application. Tests were made of the effectiveness of the bond as measured by the load required to shear the concrete along the plane of the junction of the two layers of concrete. These tests indicated that the most important single factor was the condition of the old surface—its cleanness, texture, and strength or soundness. If the surface was clean and free of a weak outer skin, very good bond was generally obtained; otherwise relatively poor bond was obtained.

These laboratory investigations are described in detail by Felt (1).

The purpose of this paper is to discuss bonded concrete construction and its various applications to pavements, to describe projects which have been accomplished, and to illustrate the essential steps in surface preparation and construction. All the jobs discussed were constructed at airports.

THIN BONDED CONCRETE RESURFACING

Although layers of concrete ½ in. thick have been successfully bonded to old pavements in both laboratory and field applications, this paper deals with resurfacings varying in depth from 1 to 4 in. because the projects were within these ranges.

In the past five years there have been five sizable jobs of thin bonded concrete resurfacing on existing concrete at airports. These were Little Rock Air Force Base, Ark., in 1955; Selfridge Air Force Base, Mich., in 1956; Campbell Air Force Base, Ky., in 1957; Bunker Hill Air Force Base, Ind., and Standiford Field at Louisville, Ky., in 1959. All these projects were accomplished under contract conditions.

The Selfridge Air Force Base Project

Though out of chronological order, the Selfridge Air Force Base project will be considered first. It is the largest in area of any project built to date and includes construction techniques common to the other projects plus problem features of its own.

In August and September 1956, a thin bonded resurface was applied to 47,000 sq yd of the aircraft parking apron at Selfridge Air Force Base which is near Mt. Clemens, Mich. Approximately 37,000 sq yd of the project area consisted of 10-in. concrete 14 yr old. The remaining area was 6-in. concrete 27 yr old. The principal defects in the pavement corrected by the resurfacing were surface scaling (Fig. 1), raveling along joints, and surface popouts over unsound particles of aggregate. There was also a considerable amount of random cracking, both transversely and longitudinally.

The Air Force specifications for the bonded resurfacing provided for preparing the surface and placing concrete of a minimum of 1-in. thickness in the following sequence of operations.

The first step in surface preparation was the removal of all bituminous material from joints, cracks and elsewhere on the pavement. The excessive amount of jetfuel

resistant sealer which had been applied, the hot weather during removal, and the irregularity of the joints were contributing factors to difficulties encountered in joint cleaning operations. This irregularity also made jointing of the resurfacing more difficult.

TABLE 1

RECOMMENDED TRIAL CONCRETE MIXES FOR THIN RESURFACING

Resurf. Thickness (in.)	Cement Content (lb)	Total Water[1] (lb)	Fine Agg.[2] (lb)	Coarse Agg. Max. Size (in.)	Coarse Agg. Amt.[2] (lb)	Air Content (%)	Cement Factor[3] (s/cy)	Slump (in.)
½	94	42	190	⅜	115	9 to 11	8.5	1 to 4
1	94	42	170	½	170	6 to 8	7.5	1 to 4
2	94	42	190	1	230	5 to 7	7.0	1 to 4
3 (or more)	94	42	180	1½	305	4 to 6	6.3	1 to 4

[1]Including free moisture in the aggregates.
[2]Based on saturated surface-dry aggregate, s. g. 2.65.
[3]Approximate, sacks per cubic yard.

Sealer was removed from the joints by plowing with an improvised "foot" mounted on the front of a light tractor, followed by two or more passes of a Tennant machine adjacent to the joints (Fig. 2), supplemented by hand-operated spud bars. Experience had indicated that sand blasting is also effective for final cleaning of joints after use of the Tennant machine.

Because of surface scale and excessive laitance in many areas it was considered necessary to scarify approximately 80 percent of the pavement surface in order to provide sound, clean concrete for the bonded resurfacing. Scarification was carried out with a fleet of four Tennant machines with heads packed with 4-in. drop forged cutters so arranged as to make a clean cut about 4 in. wide. The debris created by the machines was removed by a combination of means: compressed air and hand push-brooms to clear the immediate working area and a mechanical pickup broom for final disposal.

At this point it should be emphasized that an extremely rough surface is not necessary in order to secure bond. Scarification is used only for the purpose of obtaining a sound surface. Felt's investigations (1) brought out that a slightly roughened

Figure 1. Scaled and raveled pavement at Selfridge Air Force Base.

Figure 2. Tennant machine used for cleaning joints and grinding surface.

surface, such as produced by acid etching, is satisfacory for bonding the resurfacing.

As is frequently the case on old concrete pavements, the areas which were not scarified on the Selfridge project had various substances on the pavement surface which would likely cause bond failure. These included oil and grease, hydraulic fluid, bituminous materials and paint markings. Paint and bituminous materials and the larger grease spots were removed by spot scarification. Areas not scarified were cleaned with a water soluble commercial detergent. The detergent powder (sodium metasilicate with resin soap) was applied to the wetted pavement surface at the rate of 1 to 2 lb per 100 sq ft with a hand-operated distributor similar to a seeder. The moistened detergent was then scrubbed into the surface with a mechanical sweeper and the surface flushed with water until it showed a neutral reaction to pH paper. Thorough flushing is necessary because the alkaline detergent, if it remained on the surface, would partially neutralize the acid subsequently applied for etching the surface.

Prior to acid etching, which is the final step in surface preparation, the pavement surface was cleaned by sweeping and blowing with compressed air.

The commercial muriatic acid (27.9 percent HCl) was delivered to the job by tank truck which was equipped with a 12-ft spreader bar (Fig. 3). A force pump on the truck supplied pressure for distribution which was regulated by the forward speed of the truck to give and application of 1 gal of acid per 100 sq ft on the pavement surface which has been previously wetted. It should be noted that this is a minimum requirement. Felt recommends 1 gal of acid per 60 sq ft of pavement. As soon as all visible etching or foaming action ceased, the pavement was scrubbed with a mechanical broom and flushed with water until it showed a neutral reaction to pH paper. Because the product of acid reaction forms a jell if left long on the concrete, it is important that the surface be cleaned by flushing and scrubbing as soon as the foaming action stops.

Figure 3. Tank truck used for distributing muriatic acid.

The foregoing surface preparation items have been described in chronological order. It should be remembered that several of these operations, as well as paving , must be carried out at the same time in order to obtain good production on a project of this size.

Specially designed wood forms were used along each edge of alternate paving lanes. Paving of the fill-in lanes (approximately one-half of the pavement area) required no forms. The forms were made from 2- by 8-in. fir planks 14 ft long surface dressed down to 1¼ in. These forms were laid flat along each side of the paving lane, parallel to the old construction joints so that the 1¼-in. thickness provided the depth of the form. Each length had four steel flanges which were countersunk and bolted to the bottom face of the form. The flanges extended 3 in. beyond the outer edge of the form and were bored to receive three bolts outside the form and one bolt through the form and countersunk flange. The inner edges of forms were positioned immediately above the longitudinal construction joint and holes drilled in the concrete to receive lead expansion sleeves and lag screws for securing the forms to the old pavement. After the forms were bolted in place they were shimmed to line and grade by means of wood wedges. A steel strip ¼ in by 2 in. was inserted into the longitudinal construction joint and tacked in a vertical position on the forms inner edge to bound the paving lane and to prevent grout and concrete from running under the forms.

The wood forms used at Selfridge could not be considered an unqualified success. With occasional readjustment and additional shimming during construction, they did

serve to provide an acceptably smooth surface. Recognizing the limitations of comparatively thin wood boards when used as forms, the U.S. Air Force has specified a minimum thickness of 2 in. for thin bonded concrete resurfacing. This 2-in. minimum, instead of 1-in., will result in only slightly higher cost for material and will permit the use of sections of steel channel for forms or provide wood of a dimension that will have better rigidity.

After the forms were in place, the prepared surface was given a final cleaning. Any grease or oil spots from leaking equipment were removed with the Tennant machine. The pavement was then blown clean with an air jet.

Just ahead of placing concrete, a 1 to 1 sand-cement grout was applied to the old pavement surface (Fig. 4). The sand used in this mixture had been screened to remove the plus ⅛ particles. The grout was mixed to a heavy paint consistency in a paddle-type mixer, carried to the paving lane in buckets and scrubbed onto the damp but not wet surface with rattan stable brooms. A coating of about 1/16 in. was left on the surface. Any excess grout in transverse and longitudinal joints was redistributed with a warehouse broom. It should be mentioned that the pneumatic method of placing bonding grout has been successfully used. This method of application requires expert operation in order to control rebound and accumulation of the coarser sand particles along the form lines in a concentration likely to prevent bond. The lack of skilled operators and of proper pneumatic equipment dictated the use of hand methods of grout application on the Selfridge project.

Figure 4. Spreading bonding grout.

Ready-mix concrete was delivered to the site by transit mixers, two scheduled to arrive on the job and place concrete at the same time from each edge of the paving lane (Fig. 5). Each mixer carried 5 to 6 cu yd of concrete made from ½-in. maximum size crushed dolomite, 60 percent by weight of natural sand and 7½ bags of portland cement per cu yd. Mixing water was proportioned to give a net water content of 5 to 5.1 gal per bag of cement and a slump of 4 to 5 in. which was necessary for discharging from the mixer and for placing and finishing the resurfacing concrete. Sufficient air-entraining agent was added at the batching plant to produce an air content of 7 to 8 percent.

After a limited amount of hand spreading, the concrete was further spread during the first pass of a two-screed self-propelled finishing machine. A second pass struck and consolidated the concrete to final grade. The finishing machine was equipped with offset rubber-tire wheels which traveled on the old pavement outside the forms. This worked quite satisfactorily because it resulted in the wood forms supporting only the buoyant weight of the screeds.

After the two passes of the finishing machine, the pavement surface was given final finish with hand floats and straightedges. Surface texture was provided with a burlap drag. The resurfacing was cured with white pigmented curing compound. This method of curing was selected because it could be applied early to prevent the rapid loss of water and because it simplified subsequent joint sawing operations.

In bonded concrete resurfacing it is necessary to match exactly the joints in the old pavement both in location and kind. Longitudinal and transverse expansion joints were formed in place using wood strips which were inserted in the joint crevice of the old

Figure 5. Concrete delivered to both sides of paving lane by transit mixers.

pavement. These strips marked the location of expansion joints during paving and served as a filler in the finished resurfacing.

Transverse contraction joints were sawed with abrasive-type blades. To saw through the resurfacing and directly over the joint in the old pavement, it was necessary to carefully mark these joint locations on side forms or on the surface of adjacent paved lanes and snap a line on the finished surface of the plastic concrete to mark the exact location of the saw cut. Sawing had to be done early in order to prevent precracking over joint locations. It was done from 5 to 12 hr after paving depending on temperature and relative humidity. During cool weather the joints were sawed dry which permitted earlier sawing with a minimum of raveling along the cut.

To meet the grade of the adjacent pavement, a 3-ft ramp was built around the resurfaced area. The ramp area was routed out to a minimum depth of 1 in. and the concrete for the ramp was placed by the same procedure as the other resurfacing. Planes can enter the resurfaced area under their own power without any difficulty.

To check the thickness of the resurfacing and to provide specimens for testing the strength of bond between the resurfacing layer and the old pavement, cores were drilled from the finished pavement (Fig.6). By its appearance, the resurfacing layer is easily distinguished from the basic concrete. Fifteen of the cores showed an average bond strength of 323 psi when tested by shear stress in the laboratory. Felt's investigations led him to the conclusion that bond strength on the order of 200 psi is generally sufficient to insure adequate performance of bonded resurfacing.

After more than three years of service, the resurfacing at Selfridge Air Force Base is showing good performance. Most of the random cracking of the old pavement has appeared in the resurfacing layer. These cracks are generally close and tight and have not required grouting and sealing.

The Little Rock Air Force Base Project

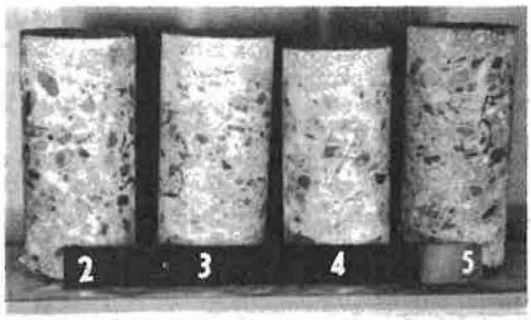

Figure 6. Cores taken from resurfaced concrete at Selfridge Air Force Base.

The bonded resurfacing at Little Rock Air Force Base, placed in early October 1955, was done to repair the surface of concrete pavement placed several months before which had frozen immediately after placing. The pavement involved was about 700 ft of a 25-ft wide paving lane. Only the immediate surface of the pavement was damaged to a depth of about ½ in. The Army Corps of Engineers held the contractor responsible for replacement of the damaged concrete which was 15 in. thick and part of an aircraft parking apron.

The contractor broke out part of the concrete which proved difficult and costly because the damaged area was on a 111-in lane bounded on both sides by concrete. An agreement was reached permitting the contractor to restore the surface of the remainder of the pavement with a bonded layer of 1 in. thick.

Preparation of the pavement required scarification to a depth of 1 in. This scarification, on a fully matured slab with large sized natural aggregate, proved somewhat tedious and relatively costly. A total of 575 lin ft of 25-ft paving lane, approximately 1,600 sq yd, was prepared for resurfacing.

No forms were necessary on the Little Rock project since the adjacent paving lanes bounded the work and provided grade and elevation for the finished resurfacing. The prepared surface was etched with muriatic acid by use of an improvised dispenser. This device was made by fastening a coiled plastic garden hose on a square of plywood which was equipped with a carrying handle. Three loops of hose on the bottom of the board were perforated and the acid forced through the hose by hand pump from glass containers mounted on the bed of a pickup truck. Acid was applied at the approximate rate of 1 gal per 100 sq ft to the wetted pavement. Workmen equipped with goggles and protective clothing spread the acid over the pavement with pushbrooms (Fig. 10). When the acid reaction ceased, the pavement was scrubbed and flushed with water until it showed neutral reaction to pH paper.

The placing of bonding grout and concrete followed the procedure described for Selfridge Air Force Base except that concrete was provided by a dual drum job mixer instead of transit mixer and that the two-screed finishing machine had two spud vibrators mounted on the front screed. The concrete was made from 45 percent ½-in. maximum size crushed aggregate and 55 percent natural sand with 7¼ bags of cement per cu yd and approximately 8 percent entrained air.

Using standard metal inserts, the joints in the resurfacing were hand formed in such manner as to provide continuity through the resurfacing layer of the joint openings in the basic pavement. The resurfaced concrete was cured with wet burlap for three days followed by an application of white pgmented curing compound.

After more than four years of service, this section of thin bonded resurfacing shows no defects of any type and is, in fact, indistinguishable in appearance from the adjoining pavement on the parking apron. This pavement has been put to a somewhat severe test by the 50,000-lb individual wheel loads of the jet bombers based at Little Rock.

The Campbell Air Force Base Project

Portions of two hardstand areas at Campbell Air Force Base, Ky., were given a 2-in. bonded resurface during the summer of 1957. The resurfacing was placed on 500 lin ft of the 25-ft center lanes of the hardstands, a total of approximately 1,400 sq yd. This was new 17-in. concrete which did not meet the finish and surface requirements of the Corps of Engineers' job specifications. Agreement was reached to permit the contractor to correct the construction deficiency by placing a 2-in. bonded resurfacing.

Paving of the outside lanes of the hardstands was deferred until after the resurface was placed on the center lanes. The construction situation allowed a raise in elevation of 2 in. to accommodate the resurfacing on the 400-ft center lane of one of the hardstands. This area was scarified to a depth of only ⅛ to ¼ in. in order to remove curing compound and faulty surface. The entire area of the other 100-ft center lane was cut 2 in. in depth so the resurfaced pavement would conform to the elevation of the original pavement. Forms were set along the sides of the 25-ft lanes and graded to an elevation 2 in. above the prepared surface.

The scarified surface was etched with muriatic acid by means of a plastic hose device similar to that used at Little Rock and the acid residue was then flushed away until the surface tested neutral.

A 1 to 1 sand-cement grout was spread on the dampened surface with pushbrooms. The resurfacing concrete was made from 50-50 crushed limestone of 1-in. maximum size and stone sand, with 7 bags of cement per cubic yard and approximately 7 percent entrained air. This low slump mixture was placed on the grout-coated surface and vibrated by conventional hand-type vibrators which were pulled through the plastic concrete in a longitudinal direction ahead of the two-screed finishing machine. A mechanical longitudinal float was used behind the transverse finisher and final finishing was by hand floats and scraping straightedges. Surface texture was provided by a burlap drag.

Joints in the resurfacing layer were located exactly over original joints by use of a transit line and sawed to a depth of 3 in. The extra inch of saw cut was to provide assurance that joint openings in the basic concrete were cleared of grout or concrete. The resurface was cured with wet burlap.

After more than two years trafficking by heavy aircraft the resurfacing at Campbell Air Force Base shows no defects of any type.

The Bunker Hill Air Force Base Project

During the early summer of 1959 a 3-in. bonded concrete resurface was placed on 45,000 sq yd of the aircraft parking apron at Bunker Hill Air Force Base, Ind. The old pavement was 8-in. concrete constructed during World War II which had developed surface defects consisting of popouts, scaling and minor spalling plus a few broken slabs requiring removal and replacement. Furthermore, the pavement required some strengthening to support the load imposed by the aircraft scheduled to use it. A design analysis indicated a requirement for a slab thickness of approximately 11 in. It was assumed that a 3-in. layer bonded to the existing 8-in. pavement would provide the required capacity and avoid the necessity for a considerably thicker unbonded overlay.

Construction procedures followed closely those previously described. Loose and damaged material was removed from the surface by mechanical scarification followed by treatment with muriatic acid. The laminated wood forms fabricated by the contractor were of sufficient rigidity to support the vibrating screed used for mechanical finishing and a level true surface was achieved. Transverse joints were formed by the use of paper inserts vibrated into the plastic concrete over the old joint locations. These inserts provided positive crack control until they were later sawed out just prior to sealing the joints. Longitudinal center joints were sawed after the concrete had hardened sufficiently to prevent raveling. The crushed limestone used for coarse aggregate served to facilitate the sawing operations.

The bonded resurfacing at Bunker Hill served the dual purpose of restoring the surface and strengthening the pavement with only a small increase in the pavement elevation.

The Standiford Field Project

During the summer of 1959 a 4-in. bonded concrete resurface was placed on 500 ft of a runway end at Standiford Field, Louisville, Ky. This resurfacing was built for the dual purpose of correcting surface defects and raising the grade of the runway end to conform to the elevation of a 4-in. bituminous overlay placed over an adjacent portion of the runway. Concrete was required on the runway ends because of utilization of the runway by the Kentucky National Guard for flight training in jet aircraft and the probability of future use by commercial jet transports.

The approximately 8,000 sq yd of bonded resurfacing was constructed using the techniques previously described. Defective surface material was removed from the old concrete by mechanical means and the prepared surface was etched with muriatic acid. Four-inch metal sidewalk forms were used on the 12½-ft paving lanes as the contractor elected to set forms to conform to the longitudinal joints in the old pavement. The concrete was struck off and consolidated by use of a hand-operated vibrating screed (Fig. 7).

Longitudinal joints were formed by a full depth fiberboard insert which was tacked to slab edges prior to placement of the alternate fill-in lanes (Fig. 8). About 1 in. of the insert was later sawed out to form a reservoir for joint sealer. Expansion joints were formed over existing expansion joints by use of a nonextruding joint filler. Contraction joints were sawed at the joint locations in the old pavement.

Figure 7. Hand-operated vibrating screed used at Standiford Field, Louisville,

PATCHING AND REPAIR OF CONCRETE PAVEMENT WITH BONDED CONCRETE

Patching and repair of concrete pavement can be effectively accomplished by the use of bonded concrete. Preparation for patching must be with the same care and attention to detail as required in bonded resurfacing and the base concrete must be structurally adequate, after removal of defective areas, to provide a sound clean surface for the bonded patch.

One recent project at a U.S. Air Force base, which included a variety of types of repairs, will serve to illustrate the essential principles of placing bonded patches.

The Seymour-Johnson Air Force Base Project

Due to the development of a considerable amount of joint spalling on some 11-in. concrete resurfacing at Seymour-Johnson Air Force Base, Goldsboro, N.C. a program of repairs to the pavement was carried out in August 1957.

The pavement involved was on an aircraft parking apron which had been strengthened by concrete overlay about a year before the repairs were made. It is not the purpose of this report to state the reason for the spalling. Similar conditions have been observed on other projects where the steel inserts for forming joints were not removed early enough and the concrete next to joints was split horizontally when inserts were pulled out. At Seymour-Johnson, when concrete was sawed preparatory to patching, the sawed face revealed horizontal laminations extending back as

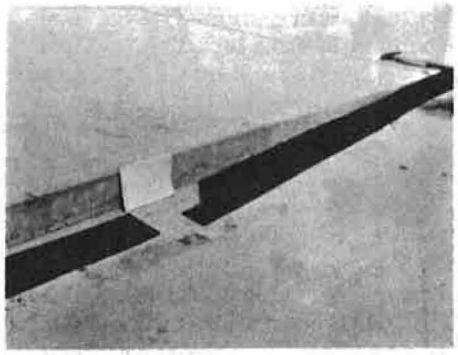

Figure 8. Full-depth joint inserts used in longitudinal construction joints at Standiford Field.

far as 10 in. from the joint. The depth of spalls indicated that the laminations occurred at depths of less than 2 in.

Although most of the patches were to repair joint defects, there was one defective area of approximately 100 sq ft in the center of a slab which was repaired. Another area (12 by 48 ft) of sound concrete was sawed out and replaced by bonded patch in order to correct an unsatisfactory drainage condition.

The defective concrete along joints was removed by use of a diamond blade concrete saw and penumatic paving breaker. A saw cut was made to a depth of 2 in. parallel to the joint at 6-in. spacing. The 6 in. of concrete between the joint and saw cut was then broken out with pneumatic tools. If the face of the saw cut showed completely sound concrete, the patch was placed at 6-in. width. If the face of the saw cut showed one or more horizontal cracks, another 6-in. section was sawed and removed (Fig. 9). This process of removing 6-in. increments was continued until a sound vertical face was obtained. Some irregular patches were formed inasmuch as pavement was sawed out only as necessary to remove the loosened surface (Fig. 10). Concrete was removed from the large areas by the same methods. Saw cuts were made 2 in. deep, 12 in. apart, and concrete was broken out with pneumatic tools.

Figure 9. Removing concrete adjacent to joints at Seymour-Johnson Air Force Base.

After excavations were cleaned, each area was thoroughly checked to insure removal of any loosened or fractured concrete that might remain. Due to the difficulty of cutting to a uniform thickness, the average depth of the patches was approximately 3 in.

Prior to acid etching, all dust was blown out with compressed air. The surface was then wetted. Acid was applied through a plastic hose apparatus from a glass carboy of muriatic acid (Fig. 10). It was difficult to broom acid uniformly on the irregular surface, consequently more than the usual amount was used. Applied at the rate of approximately 2 gal per 100 sq ft, the acid was broomed about until adequate coverage was assured. Brushes with fiber bristles were used to apply acid to the cut faces of the concrete.

Figure 10. Prepared patch receiving acid treatment. Note improvised acid dispenser at right.

Figure 11. Applying bonding grout prior to placing patch.

Acid was removed from the excavations by first filling the depression with water then applying a high pressure jet to blow out the acid water and clean the surface. This was contiuned until a neutral reaction to litmus paper was obtained. A 1:1 sand-cement grout was brushed into the surface, indlucing the vertical faces of saw cuts (Fig. 11).

Patches were placed with properly proportioned concrete containing 1-in. maximum coarse aggregate, 7 bags of cement per cubic yard, and 5 percent entrained air. Water-cement ratio was maintained at not more than 5 gal per bag of cement. Concrete was placed at 1¼-in. slump and vibrated for leveling and consolidation with a portable vibrator (Fig. 12). After vibration the concrete was struck-off with a wood 2x4 and hand-floated (Fig. 13). The large areas were finished with a 10-ft straightedge. Surface texture was provided by brooming.

Figure 12. Hand vibrator used to consolidate concrete in patch.

During patching operations no attempt was made to keep existing joints open. Instead, joints were reformed by sawing some 7 or 8 hr after the patches were placed (Fig. 14).

Wet burlap cure was applied for three days followed by application of white pigmented compound. Patches were allowed to cure for 2 weeks before plane traffic was resumed.

After more than two years of service under heavy bomber traffic, these bonded patches show no defects of any kind.

Figure 13. Finishing patch with hand float.

Figure 14. Sawing patch placed on both sides of joint.

CONCLUSIONS

Resurfacing or patching of concrete pavements with bonded concrete has been proved feasible in both laboratory investigations and field construction projects.

When the purpose is only to even up rough surfaces, a thin resurfacing layer will perform as well as, and in many cases better than, a thicker slab, provided that adequate bond is obtained between the old and new concrete. In many cases, especially when the concrete to be resurfaced is part of a larger area, use of the thinner overlay avoids the problem of adjustment of grades on the perimeter of the resurfacing.

If the satisfactory performance of resurfacing or patching with bonded concrete depends on the securing of adequate and uniform bond between the two surfaces. If the essential operations are carried out on a clean sound surface with good workmanship and high grade materials, the degree of bond essential to satisfactory performance can be obtained.

REFERENCE

1. Felt, E.J., "Resurfacing and Patching Concrete Pavements with Bonded Concrete." HRB Proc., 35:444 (1956).

HRB:OR-354