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Discussion.

The Authors introduced the Paper with the aid of a film and a series of lantern slides.

Colonel W. C. Carey, United States Army, observed that he wished to congratulate the Authors on the presentation of a very interesting Paper and the Road Research Station for investigating such an important subject. It had pleased him very much, and would, he thought, please most engineers, to find that the veil of mystery attached to those processes had been removed. When he first heard about them he was rather annoyed because they always seemed to hinge upon a special road oil. He was surprised to find in England that it was possible to mix a tar product with an asphalt product. In America the tar people and the asphalt product people hated one another very cordially.

In the United States wet aggregates were used to some extent with asphalt or bitumen cut-back with kerosene, naphtha, or other petroleum solvents. Generally, the materials were mixed in place and the moisture was removed by aeration as a result of constant mechanical manipulation. Such mixtures were largely used as stabilized bases as well as open type mixtures of the asphalt macadam type. Some of the dense type mixtures were not too satisfactory and they sometimes exhibited the troubles to which the Authors had alluded in their remarks on the normal behaviour of cold wet aggregates when mixed with liquid asphalt. Of course, when these mixtures were made under good conditions those troubles did not materialize.

One American company had produced a special line of cut-backs. They were designated by adding the letter " W " after the standard formula to indicate their suitability for use with " wet aggregate." There again was the element of mystery which he did not much like. Even

those special cut-backs did not work perfectly ; they simply worked better than the standard, and that was all.

It was clear from the Paper that the essential things were the lime and the creosote. One thought which had occurred to him in connexion with the Paper was that some American experience had indicated that tar or tar products had some valuable properties in wetting wet aggregate in preference to water. In preparing bases for pavements in America a material called a " primer " was used. That was sprayed at the rate of, perhaps, $\frac{1}{4}$ gallon per square yard, and was supposed to penetrate the soil for a certain distance and bind together a waterproof surface on which pavement could be laid. Two materials were used for that purpose. One, a medium-curing bitumen cut-back, and the other a liquid tar ; the latter being very much preferred by most engineers. He was now clear in his own mind as to the sound basis for that preference, after studying the Paper.

He believed that there was an important future in the conception of wet aggregate mixes for producing stabilized bases. Those bases, with a fairly thin bituminous surfacing, offered an important application of that principle to American conditions. He would not be surprised now to find that creosote might be mixed with bitumen even in America.

In reading the Paper, the idea had occurred to him of combining the advantages of the wet sand process with another simplified mixing process, and he hoped that the Authors might mention that briefly in their reply. American engineers in Great Britain were using hot asphalt mixtures, and they had experienced all the usual difficulties in making hot bituminous mixtures. They had good plant and the best materials, but they did not have many people who knew much about the subject. Difficulties had also arisen in the transport of asphalt, and the final result was that the output of those plants was not what it should be. He recalled the type of mix evolved several years ago in Mississippi, which was called " warm mix." The conventional hot mix asphalt was used with natural sand gravel aggregates. The weather was cold and wet and the output of the plants had decreased to an alarming extent. The engineers and contractors together conceived the idea of using a cut-back instead of a straight asphalt, and, instead of drying the aggregate completely, stopping the drying operations at a point where not more than 2 per cent. of moisture would be left in the material. The material was passed through the mixer and the cut-back was heated to about 200° F. and then introduced into the mix. The resulting mixture contained from 1 to 2 per cent. of moisture and perhaps 0·5 per cent. of volatile matter and was delivered at a temperature somewhat lower than 200° F. It was spread, laid, and compacted by the same methods as the hot asphalt mixture previously employed. Within several days after laying, it contained practically no volatile matter and perhaps 0·5 per cent. of moisture. Actually, after several days the final product was indistinguishable from

hot asphalt mix. He wondered whether the combination of that warm mix conception with the wet sand mix conception might not work out very well in actual practice ; instead of using the American type of bitumen cut-back, made with petroleum solvents, a bituminous cut-back, with creosote as the solvent, would be used with perhaps 1 or 2 per cent. of hydrated lime in the mix. That combination might have interesting possibilities in view of the fact that the use of a warm mix had a tendency to increase plant capacity by from 50 to 100 per cent.

He wanted to add that the United States forces had used the wet sand process in their work in Great Britain. They had paved one aerodrome by that process, and it had worked out rather well. He hoped the Authors would say a word about his proposal of combining the Mississippi warm mix with the ideas they had elaborated in the Paper.

Major R. W. Grigson said that he thought the Paper was of particular interest because the processes described had both immediate war-time application and a place in the technique of peace-time construction. The Authors deserved the thanks of both military and civil engineers. They had modestly made only a brief reference to the advantages and prospects which resulted from their research, and he desired to add a few words on that subject. In 1940–41 he was with a unit engaged on the construction of airfields in a notoriously wet part of the British Isles. Speed in construction was urgent, and, lacking sufficient plant themselves for military purposes, the engineers were largely dependent on a number of civilian firms for their supplies. Every available plant was pressed into the service, and in many cases the drying facilities were quite inadequate, with a consequent reduction in output. A knowledge of how to coat wet stone would have been of the greatest value. The saving of drying-plant was probably of greater significance to the military than to the civil engineer. He would be interested, therefore, to know the quantity of fuel consumed in drying and heating a ton of stone over, say, a period of twelve months.

Another peace-time advantage which occurred to him was the elimination of the necessity for providing cover for stores of aggregate.

The military significance of the processes having been realized, steps had been taken to make them widely known to the Royal Engineers, and officers had received theoretical and practical training at the Road Research Laboratory and on the site. Two complete airfields, as well as some miles of roadway, had been constructed by the Royal Engineers using the wet-sand process.

The Authors had stated that, in connexion with wet-sand mix construction, the usual procedure had been for a consolidated thickness of about 4 inches of coated sand to be laid straight on to the level sand formation. As the primary function of the sand carpet was to provide a wearing surface, that seemed excessive. Was there any justification for it ? When the compacted sand base had been laid should not the thickness

be reduced to 2 inches, or even 1½ inch ? That was of particular interest because it was necessary to cut down the transport of materials to the minimum.

The Authors had also stated that the material, when first laid, was a little soft, particularly with the usual cut-back bitumen, but that within a few weeks the consolidated material hardened enough to carry heavy bomber and lorry traffic. A few weeks' delay might not be of great significance in civil construction, but it might prove a serious objection in military work, and he would like to have the Authors' views on the following proposals to accelerate hardening: the use of up to 5 per cent. more hydrated lime to act as a stiffening agent in the binder, as described in the Paper for mixing wet-stone aggregate; when using sand in a dry condition, to increase the moisture-content up to about 5 per cent.; the reduction of the binder-content to 4 per cent., or even less if stability was not too adversely affected.

He had noticed that mixes with a tar binder seemed to harden more rapidly than mixes with a cut-back bitumen. Could the Authors explain that ? In the film illustrating the wet-stone process the material being spread seemed rather stiff. Was that, in fact, true, and was any undue stiffening of the mix likely to occur in transport or storage ? That was a practical point of great importance.

Knowledge of the behaviour of wet stone aggregate, particularly in the larger sizes, was more limited than knowledge of wet-sand mixes, but he hoped that that would soon be rectified by programmes undertaken by civil and military engineers in the light of the information furnished in the Paper.

Mr. W. L. Campbell observed that he was uncertain of the extent to which Part II of the Paper overlapped Part I. He thought it was important to obtain as clear-cut a distinction as possible between the gradings of the aggregates which came within the wet-sand process and the wet-stone process. For the former he suggested that the mix should be allowed to include not only sand but also gravel-sand aggregates containing up to 40 per cent. larger than ⅛ inch, for mixes using aggregates of that nature had essentially the characteristics of a wet-sand mix. For the wet-stone process the mix should include only those aggregates in which the stone or chippings formed the skeleton, with fines in quantity never more than would fill the voids.

The distinction which he had tried to draw was important in a number of respects. Firstly, experience with the wet-sand process had shown that the same viscosity of binder could be used in spring, summer, autumn, and winter. That was not so with the wet-stone process. Secondly, in the gravel-sand mix (the gravel not exceeding 40 per cent. of the total mix) it was unnecessary to screen the gravel from the sand and to follow the rather elaborate mixing technique shown in the film. With those gravel-sand mixes the whole mixing could be done in one operation. Admittedly the

gravel part remained uncoated, but he thought that was immaterial, because the gravel remained firmly embedded in the sand mastic.

Thirdly, for the wet-sand process he would hesitate to substitute cement for lime, as could apparently be done in the wet-stone process.

As regards wet stone, his first-hand experience was very limited, but so far as it went, he thought that Table I and the text accompanying it stressed rather unduly the control necessary on the viscosity of the binder. The impression was given that within the range of 5° to 20° C. different binder viscosities were required, of 5°, 10°, 15°, and 20° C. He would suggest that two viscosities would serve the purpose; and if the Authors considered that they would then not be sure of effecting complete coating, he would ask whether complete coating was necessary in a mix of that nature, and whether 80-per cent. coating would not be safe and adequate, especially for base-course purposes. It was in the larger stone sizes that it appeared to be difficult to obtain complete coating.

The viscosities shown in Table I fell, perhaps, too low. He had seen ¾-inch wet gravel practically 100 per cent. coated with binder of 30 seconds viscosity at 30° C. In the case of granite the viscosity had had to be reduced to 15 seconds, and admittedly then only 80 per cent. coating had been obtained. Both those mixes were laid in 1940 during frost on a road carrying considerable traffic, and when last inspected, about six months ago, that road was in sound condition. He mentioned that small experience with hesitation, but he felt that with the low viscosities shown in Table I the mixes might be unduly slow in setting. What was the Authors' experience as regards the rate of setting with stone and chipping mixes?

As regards wet sand, the Authors had stated that when the mix was first laid it was a little soft, and they had also stated that in the sand containing more than about 7 per cent. of material passing 200 mesh, difficulties had occurred owing to the surfacing remaining soft for long periods. Both comments were correct, but wet-sand mixing had been going on now for 3 years and everybody concerned regarded themselves as 3 years wiser. It was now possible to design the wet-sand mix so that any desired degree of rate of set of the material could be obtained, and also any degree of stability.

Referring to conclusion (i), on p. 22, *ante*, the process of coating cold, wet sand was evolved just for that purpose. It had been discovered later that the wet mix possessed properties which were entirely lacking in a mix similar in every respect except for the absence of water; and the particular value of the wet-sand mix for peace-time work perhaps lay in the fact that it had something—a structure—which a dry-sand mix had not; the fact that it could be made without driers would then be of incidental value. He was not sure to what extent the remarks he had just made applied also to the wet-stone mix. That should possess in

some degree the same setting characteristics, and possibly the Authors could express an opinion on that point.

Mr. J. Blott observed that the Authors had concluded that an essential factor in the success of the lime process was the presence in the binder of organic acid materials which, with the lime, produced an emulsion of water in the binder during the mixing. It was quite true that an emulsion of water in oil was formed, but it was possible to adduce arguments against that being the most important factor. On mixing certain oils with wet aggregate, a fine emulsion of water in oil was obtained, but the aggregate was not coated. On the other hand, certain cation-active dopes encouraged wetting, but if the binder were examined after the mixing little signs of emulsification of the water in oil might be found. Therefore it did not necessarily follow that emulsification was an essential factor in those other cases, and it was not necessarily the most important factor in the lime process. If emulsification were the most important factor, then it would not be expected that different aggregates should show different behaviours. But the Authors had shown, in *Figs. 4*, that certain types of stones gave satisfactory results, and that could be seen even more clearly if stones were crushed to the fineness of sand. With a limestone sand a very inferior coating was obtained.

Perhaps the strongest argument against the emulsification theory was that once those aggregates had been coated satisfactorily they could be immersed in water without stripping.

The Authors' conclusion that emulsification was the essential factor was based mainly on *Figs. 1*, wherein a change in the contact-angle due to the presence of lime was shown to be slight. In the conditions of those experiments the oil was advancing over a wet glass surface, and it was well known in other connexions that an advancing contact-angle was greater than a receding contact-angle. Was it not possible that the main effect of the lime process was to reduce the receding contact-angle, and not the advancing contact-angle ? If the contact-angle were modified, then one could be certain that subsequently, when the mixture came into contact with water, it would not be displaced ; but if it were merely a question of emulsifying the water and causing the oil to coat the stone, stripping of the binder might occur.

The hardening of the wet sand mixes by the loss of volatile oils from the binder did not seem to be a very important factor in comparison with the other influences at work. A certain degree of mystery still existed about the wet-sand mix, even though one of the veils had been lifted. It rather seemed that the lime and any other filler associated with the sand, such as clay, became dispersed in the binder and imparted to it a structure which conferred considerable mechanical strength on the mixture, so that it behaved like Portland cement. Where water for the setting was available, once such setting had occurred, the water could be lost without any loss of structure. As a result of that structure with the lime, the load-

bearing capacity of a wet-sand mix might be four or five times that obtainable with the same proportions of dry sand, lime, and binder. Water, instead of introducing a difficulty, was essential for obtaining the best results from that process, and if the water was not present, it was desirable to add it in order to obtain the advantage of increased stability. The Authors, in their conclusion, had made what was rather like an apology for those processes of coating aggregates, but some reference might have been made to the advantages in respect to stability.

Mr. Robert Slater considered that insufficient full-scale work had been done with the wet-stone process to indicate whether it would revolutionize peace-time practice. The most that could be done was to provide a kind of insurance for peace-time work. Specifications for re-carpeting almost invariably included the phrase: "The aggregate should be dry and not exceeding 150° F." He thought that if 1 or 2 per cent. of hydrate of lime could be introduced into the mix as a standard practice it would be useful when the stone was damp. He did not see what harm would result if the stone were not damp. In the mixing technique with wet stone and bituminous binder the important thing was the viscosity of the binder, because all the time one was trying to mix materials and lay them on a road which had to be opened for traffic within a few hours of laying. Therefore, what he had tried to do in the mixing was to find the highest viscosity which could be used whilst coating the stone-sand to about 90 per cent. of its area. In that way one could obtain good compaction on the road. Mr. Campbell had pointed out that the viscosities mentioned in Table I were very variable, and also very low. The purpose of Table I was to show that different aggregates behaved differently in that respect; the viscosities were those from the original laboratory mixer, and ranged from about 10 to 60 seconds at 30° C. But in Table III the higher viscosities were of the order of 100 seconds, which fitted in with the figure quoted for normal road work. The value of 90–110 seconds at 30° C. mentioned in Table III was, he thought, suitable for work done in summer time. He had carried out work in October with similar mixes and had found that that viscosity could not be used—certainly not in the early morning. The procedure adopted in the morning was to coat with tar at about 80 seconds viscosity to which had been added a small quantity of creosote flux; and although a variable viscosity was used, it was not something which was impossibly complicated.

With regard to the laying properties of those materials, no difficulty had been experienced with mixes having a predominating sand-content or a predominating stone-content (including up to 25 per cent. sand). Mixes containing approximately equal proportions of stone and sand, however, had been found to be somewhat stiff for hand laying, though they could probably be laid satisfactorily by machine.

Although a great deal of laboratory work had been carried out on the principles of the wet aggregate process, there was, no doubt, a need for

some really large full-scale work in order to ascertain the practical difficulties.

Mr. H. S. Keep agreed that although a great deal of work had been done on the wet-sand process in which the aggregate was sand, very little full-scale work had been carried out with the larger materials. It had been hoped to extend the work during the past summer, and now the hope was that arrangements could be made to do so during the next season. So far rather small mixers had been used, and it remained to be seen whether the coating could be effected satisfactorily with full-scale plant.

The Authors had stressed the very thorough mixing which was required, and the film had shown that a certain type of mixer spread the globules of binder over the stone. Generally the smaller the mixer the more thoroughly could the mixing be carried out. It might be found that the time of mixing seriously retarded the output, and that would have to be carefully considered in assessing the value for peace-time work in comparison with the normal hot mix. The loss of time might go far to offset the advantage due to the saving in fuel and plant. He hoped it would not be so.

The spread of the film of binder over the surface of the stone reminded him of some work done in 1934, when an attempt was made to coat gravel with cement. The results were not very satisfactory. Two sections were put down, one of which showed a definite improvement, whilst the other did not. The engineers were a little puzzled at the time, and he thought they were rather groping around the lime theory; but probably the explanation was that there was not the mixing action to do the spreading. Although the tar was getting better acquainted with the stone, it was not very intimately associated with it.

A very considerable area had been laid by the wet-sand process. The original work was carried out on a fine sand which was very uniform in its character, and the results generally were good. Much greater difficulty was experienced later on a site where the sand varied considerably from point to point. A word of caution should perhaps be given. Whereas it might be very convenient, and effect a considerable saving in transport, to use locally available materials, difficulties arose if those materials varied in quality in a way which would not occur normally with materials derived from a quarry.

Dr. L. Maddison observed that under war conditions it might be necessary to produce a surfacing rapidly, possibly under very adverse conditions. Therefore, anything which would eliminate the effects of stripping, as shown by the tests described, should be attempted. The addition of wetting agents certainly did that. They appeared to act by reducing the interfacial tension, and that could be exemplified in the case of calcium phenate, as mentioned in the Paper. If, instead of using hydrated lime, calcium phenate were added the wet stone the binder behaved in the

same way as if lime were added. If the calcium phenate was added to the binder itself it had a different effect.

With regard to the mechanism of the process, and the question whether the emulsion formation was really part of the mechanism, in the circumstances mentioned by Mr. Blott those agents were actually adsorbed on the surface of the stone with the complete removal of the water thereon, and they caused the binder to stick to the hydrocarbon molecules on the surface of the stone. Such a process depended upon the stone-binder relations rather than upon the water-binder relations; in the case of the lime process, though the type of stone could not be neglected altogether the coating appeared to depend mainly on the water-binder interfacial relations.

Mr. F. L. D. Wooltorton observed that the Authors had stated that *Figs. 3* and *4* illustrated different degrees of coating which might be obtained with different aggregates, but that an explanation was not likely to be forthcoming until a more comprehensive series of aggregates had been studied. He had to work largely with limestone chippings or aggregates. When those came to the road they were covered with a sheath of very fine dust which probably had a *p*H value of from 9 to 11. No matter how much that aggregate was washed or dried, the fine dust film remained and the bitumen could not be caused to stick to the stone. To overcome that difficulty some engineers had adopted a universal application of tar instead of bitumen. The tar stuck to that particular stone. Cut-backs, whether manufactured or local products, were also useful. That seemed to run parallel with the Authors' statements that when an alkaline substance was added to the wet aggregate, if bitumen was used as a binder a wetting agent was incorporated; and further, that when a tar binder was used no wetting agent was necessary. Under such conditions tar seemed to be a very useful binder.

Had the Road Research Laboratory ever investigated the effects of the replaceable bases, which might be present on the stone, on the affinity between the stone and bitumen? He was sure that the thin layer of dust on the stone, which could not be removed, had some effect upon that affinity.

Dr. G. E. Foxwell asked what quantity of tar acids—phenols—should be present in the tar. Should it be materially more than was required to combine with the added lime? Was the process affected by the nature of the tar—horizontal, vertical, or coke-oven?

Mr. L. G. Clugston observed that it would be useful if the Authors would specify the creosote used. Some reference had been made to adding hydrate of lime to a "dry" aggregate that had really not been dried. He assumed that what was meant was that it had been through the drier but condensation had taken place—known in the trade as "sweating." The addition of hydrate of lime might have had the effect of a hot mix the

next day. No reference had been made to the distances over which the material could be hauled. Could it be hauled 30 miles ?

*** **Mr. H. J. Hodsman** observed that it was normal practice to control the serviceability of tar binders by means of distillation processes, although the use of additions had been proposed, as could be realized from the Patent literature. The possibility of synthesizing suitable additions within the tar itself had not escaped notice, but there had been reluctance to recognize the merits of the simplest method, namely, to take advantage of the reaction between lime and the constituents of tar. His interest in the matter had arisen nearly 10 years ago, in the course of laboratory work done in the Fuel Department of the University of Leeds, the essential features of which were described in British Patents Nos. 471216 (1936) and 501301 (1937), which unfortunately did not appear in the Authors' references. Full-scale trials were made on public roads in Leeds. The Authors had chosen to study the possibility of using lime to provide a bituminous coating on such unattractive material as wet sand. It was already known to Mr. Hodsman that the incorporation of lime improved the adhesion of tar to stone, and its resistance to displacement by water : that was an early discovery.

The Authors had devoted some space to the mechanism of the process whereby lime and tar acids brought about desirable changes in the properties of tars, and even bitumens, owing to the formation of calcium salts of tar acids (either present or added). Their views were substantially in accord with those set out in the Patent Specifications mentioned above. The Authors appeared to regard the process as merely a wetting phenomenon. Mr. Hodsman had evidence that when lime and tar were brought together under suitable conditions changes more involved than the reaction of the lime and tar acids took place. Those changes could even affect the fluidity of the tar, apart from the viscosity, and that had been shown to improve the serviceability of the binder—reducing its tendency to " bleed " and increasing its resistance to displacement by water. Dr. Lee had previously shown that adhesion was dependent upon viscosity, and Mr. Hodsman's experience showed that viscosity could be increased by the treatment of tars with lime. Therefore it was surprising that the Authors had not emphasized that point.

The Paper was important as showing what might be achieved by the intelligent application of lime in the treatment of tar even in unfavourable conditions. That invited curiosity as to what might be done with lime under conditions nearer normal. Tests had been made on roads in Leeds over the past 7 years. In the few road tests made on Mr. Hodsman's process, surfaces which had been under traffic for 5 years had revealed benefits obtainable by the use of lime in comparison with other road surfaces made by normal practice. In that connexion mention had been

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*** This contribution was received in writing.—SEC. INST.C.E.

made in the Paper of a material which required "a few weeks" to set, and Mr. Hodsman wondered what was the normal time required to attain serviceability. His experience was that setting-time could be shortened to any desired point. A road surfaced in 1939, and opened to heavy traffic immediately after laying, had survived all the changes of temperature, weather, and traffic conditions without showing at any time either deformation or bleeding.

After several years of effort to draw attention to the possibilities of the use of lime, he was gratified to find that the Authors had been able to confirm so much of what he had discovered during those years.

Dr. Lee, in reply, said that the points made in the discussion would help his colleague and himself in the further work they were carrying out.

Colonel Carey had spoken of the mystery which surrounded the subject. That mystery was not yet completely solved, although its solution might not be very important from a practical point of view. One mystery related to the fact that stones might have the same ground-temperature and the same predominating chemical composition and yet behave quite differently.

With regard to the Mississippi mix, the question as to whether one should change over to the cold mix depended upon the vehicular traffic conditions. If the traffic were very intense he would prefer the warm mix; otherwise he thought the wet mix or a combination would be helpful.

Certainly dust had an effect upon the coating of the stone, but it was not the whole of the answer to the problem. Mr. Wooltorton's particular experience fitted in generally with the explanations given; but the dust was not the only explanation. In dealing with different stones, one particular sample of quartz had a film of dust upon it, and it was thought that it would only be necessary to remove the dust to obtain the desired result: but when the dust was removed trouble was still experienced.

Major Grigson had asked a number of specific questions. The Authors had not had much experience in regard to the quantity of fuel required for heating. From information kindly supplied by Mr. Barnes and Mr. Tebbutt, both of whom had had considerable experience with bituminous surfacing materials, it appeared that the amount of fuel required depended upon the type of binder, the quantity of fine aggregate in the mix, and the time of year, as well as upon the moisture-content of the aggregate. For example, tar surfacings containing not more than 10 per cent. of fine aggregate would require about $1\frac{1}{2}$ gallon of oil per ton of mixed materials; those containing 25 per cent. of fines would require $2\frac{1}{2}$ gallons of oil; and those containing 50 per cent. of fines about 3 gallons in the summer and 4 gallons in the winter. With bitumen binder those figures would be increased by about $\frac{1}{2}$ gallon. It was interesting to note that a saving of 2 gallons per ton corresponded to about 1,800 gallons per mile of $\frac{3}{4}$-inch carpet on a 30-foot road.

With regard to the thickness of compaction of the wet-sand base, he himself had wondered whether 4 inches was not rather excessive. It

might be reasonable, but he believed there was something in Major Grigson's view that it could be reduced. The deciding factor was probably the practical evidence of construction. For some purposes at an aerodrome 4 inches was probably a reasonable thickness.

The softness of the material after it was first laid was a matter of some importance. The addition of extra lime would cause more rapid setting, but the extra lime would have to be added after the first coating. If an attempt were made to add all that lime at once such a high viscosity would be obtained as would probably prevent coating.

A specific answer could not be given to the question of the hardening of the tar and bitumen. The small quantity of work carried out with tar had been done with a tar of higher viscosity than the bitumen.

The apparent stodginess of some of the mixtures was probably due to the use of a higher-viscosity tar.

Mr. Campbell had had a wide experience with sand mixes and his point concerning the sand mix was of interest. The viscosities mentioned in Table I were for 100-per cent. coating of stone. The Authors set a definite standard, and if one was satisfied with a lower percentage of coating the limits of viscosity could be increased. Dr. Lee agreed that for practical purposes a lower percentage of coating could be accepted, and therefore a higher viscosity could be used.

With regard to the rate of setting for graded surfacings made with high stone-content, the sections which were laid carried the traffic immediately the job was finished and quite a short time after the roller had gone over it; and although the traffic was rather heavy no sign was apparent of any deformation in the tracks where the traffic-density was high.

Mr. Blott's criticism of the mechanism of coating was interesting. Dr. Maddison had replied to that, but Dr. Lee thought that whether it was emulsification or not depended upon the reagents used; his own opinion was that emulsification was an essential part of the lime process; in the particular case mentioned by Mr. Blott, the water had really no affinity at all for the treated stone. As to whether the matter was one of advancing or receding contact-angle had not been determined: no measurements had been made of the receding angle. From the coating aspect, the advancing angle was the one that mattered. Possibly measurements of the receding angle would throw more light on the process. He agreed that the process itself was one in which a structure was formed in the binder, and that structure would help to resist subsequent displacement. There was a point, of course, whereat it might be suggested that the emulsion itself helped to form the structure.

The statements made in the summary of the Paper were, perhaps, too guarded, but he agreed that the process had certain possibilities for the future. Further practical experience would be obtained. He felt quite optimistic about the method, and there was nothing to suggest that it

would not be applicable for normal traffic. He had taken the opportunity, on one occasion, to have a mix made in a 30-cwt. mixer, using a slag aggregate, and that was actually the first time that had been attempted. The attempt was successful, and he understood that the surfacing was still in good condition. Difficulties arose in the sand mix if the sand varied in the manner described by Mr. Keep.

Dr. Lee had not referred to the patents mentioned by Mr. Hodsman, as they did not bear on the problem of coating wet stone with bituminous binders; they described a method of producing a structural viscosity in certain types of tar.

The minimum quantity and type of phenol necessary for the efficient working of the lime process had not been fully investigated. Sufficient phenol had to be present at the interface to react with the lime in solution; taking the tars with which the Authors had been working, good results had been obtained with a phenol-content of the order of 2 per cent. Although good coating could be obtained with any phenol, best results were given with the higher molecular weight phenolic materials; the usual commercial creosotes contained a range of phenols sufficient to make them generally satisfactory as fluxing oils. No differences had been observed arising from the use of different types of tar, such as horizontal, vertical, or coke-oven.

The Authors would expect the difficulties caused by the sweating of aggregates to be overcome by the use of lime. The amount of moisture present would in any case be relatively small, and as the problem was primarily the coating of the aggregate, and not the rapid development of a structure in the binder, the use of lime would be expected to be beneficial in those circumstances.

Although the Authors had had no experience of long-distance haulage, there would appear to be no reason why the material could not be hauled successfully for distances of 30 miles.

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