

Bridge Paints.

(Space does not permit of full details of all the paints, but these will be supplied on request.)

<i>(1) Metallic Zinc/Chlorinated Rubber.</i>		<i>Percentage by Weight.</i>
Zinc in oil (7 per cent. raw linseed oil)		62.0
Chlorinated rubber solution		9.1
Cereclor		1.7
Xylene		27.2
<i>(2) Basic Lead Sulphate/Red Lead/Asbestine in Linseed Oil.</i>		
Basic lead sulphate in oil (8 per cent. raw linseed oil)		34.4
Red lead in oil (7-9 per cent. raw linseed oil)		46.8
Asbestine in oil (50 per cent. raw linseed oil)		4.0
Raw linseed oil/boiled linseed oil (3/1)		13.7
Liquid drier		1.1
<i>(3) Red Lead/Metallic Lead in Linseed Oil.</i>		
Metallic lead in oil (6 per cent. raw linseed oil)		86.4
Red lead, dry.		1.8
Raw linseed oil/boiled linseed oil (3/1)		11.4
Standard drier		0.4

Discussion.

Mr. Fancutt introduced the Paper with the aid of a series of lantern-slides and a film. He observed that he particularly desired to emphasize that the prevention of corrosion should be started in the early life of a structure. Even with paints of ordinary quality—straightforward linseed oil paints—it was possible to obtain a life of from 5 to 6 years without difficulty, provided that some consideration was given to the preparation of the steel in the initial stages. Incidentally, that was very important from the maintenance point of view, because if it were possible to extend the useful life of paint coatings by 100 per cent., or even more in some cases, a dividend would be received in the form of reduced maintenance charges; and if it were possible with the aid of surface pre-treatment to extend the life of very ordinary paints to that extent, paints were on the market and others were in course of preparation which would be capable of extending the life very materially. If the Authors could help in any way in impressing upon engineers in general the importance of surface preparation and the necessity for corrosion to be tackled at the commencement and not after it had begun its ravages, they would feel that their work had been of some use.

Mr. Donovan H. Lee observed that the Paper was fully up to the standard which was to be expected from the Authors' almost unique experience of corrosion and paint problems. He considered that it was of great importance, especially at the present time, to have reached a stage where a satisfactory inhibiting primer paint was available which was

not entirely lead. In addition to the well-known disadvantages of red-lead paints from the point of view of health and their settling properties, most of such paints took some time to harden and needed oxygen rather than heat to dry them. If, as the Authors had suggested, the time was near when composite pigment paints, partly of red lead and partly, say, of red oxide, could be used successfully to give protection against corrosion equal to that of red lead alone, that would be of great national importance now that supplies of lead were short and linseed oil was in short supply.

He would like to have a little more information than was given in Tables I-III about the relative increase in durability of phosphated steel in comparison with plain steel which had not much scale on it—just as it would be received in a works. In so far as metal protection on steel was concerned, it would be interesting to know with what success the Authors thought aluminium-clad steel sheets could be used, if made commercially available?

Table V did not show the results which might have been expected. The fact that a surprising number of panels had not failed at all after 48 months did not seem to be in accordance with the statement in the Paper. Could the Authors add some further explanation?

Mr. C. A. F. Hastilow observed that, as a paint manufacturer, he could hardly be expected to be enthusiastic about the possibilities of using metallic coatings, but was very glad that structural engineers and others who were responsible for the maintenance of ironwork and steelwork were having their attention focused upon the necessity for giving a little more time and thought to paint. The question of the pre-treatment of structural steelwork had been rather neglected, though the position was quite different in industries which used metal sheets and metal pressings. In the motor-car manufacturing industry, for example, paint films had been devised and paint processes had been developed as a result of which the paint would probably outlast the rest of the car. That was primarily due to the valuable methods which had been devised for pre-treating the metal panels. A motor-car manufacturer would no more think of omitting pre-treatment of the panels than of omitting any other important part of a car. The methods of pre-treatment were not exactly similar to those recommended in the Paper for structural steel, but the principle was the same and all-important: to obtain first-class adhesion of a paint film, irrespective of its formulation, to any sort of surface, it was essential for that surface to be properly prepared to receive the paint.

That had been exemplified by experience during the war. Aluminium and light alloys were very difficult materials in regard to satisfactory paint adhesion, and when the bomber raids over Germany were beginning to develop, it became necessary to devise methods of ensuring that the camouflage paints, which were a very important element in the protection of the bomber crews, would adhere satisfactorily to an aluminium surface. Excellent non-reflecting paints in very intense shades of black were

developed, but initially considerable difficulty arose because patches of paint came off during operations, and the bright metal surface exposed was illuminated by enemy searchlights. Therefore the pre-treatment of the aluminium and light alloy surfaces became a matter of very great importance. Satisfactory methods were devised, and towards the end of the war little or no difficulty was experienced with regard to adhesion of the cellulose paint films used for camouflage purposes.

From the point of view of the maintenance of structures, the problem was becoming of even greater importance owing to the shortage of raw materials. Raw materials for the manufacture of paint were likely to be scarce for at least 2 years, and possibly for even longer, and therefore all responsible for the maintenance of buildings and structures should see (a) that the paint used by them was of first-class quality, and (b) that it was properly used.

Under (b) Mr. Hastilow would attribute considerable importance to the preparation of the surface; and the flame-cleaning process which Mr. Fancutt had developed seemed to offer extraordinary possibilities in that direction. If a proper painting system were used, with materials of good quality, it should be possible to avoid repainting for long periods.

If the surface of structural steel work were sufficiently well prepared in the first instance, before the priming paint was applied, and that was followed by a proper system of painting, using first-class material, it should be possible to maintain a structure in a good state of preservation, by renewing the finishing coat of paint every four or five years. The application of a finishing coat in that manner should be made before the existing finishing coat had disintegrated or its adhesion had become impaired. Burning off and complete repainting would probably then be necessary only after intervals of 20 years. By that means the expensive cost of preliminary treatment, whether by flame descaling or other method, would be spread over a long period.

Considerable research work was being carried out in regard to the most desirable formulations for paints for the protection of iron and steel, and Mr. Hastilow had little doubt that, as a result of the co-operative work by the Authors and by members of the paint industry, the Paint Panel of the Iron and Steel Institute Corrosion Committee would have some very interesting and educative developments to report.

Mr. P. S. A. Berridge observed that the subject of removing scale before fabrication or at the very beginning of the life of a structure was of considerable interest to him. In 1937, as a result of a questionnaire issued to most of the railways in the world, the Germans and the Austrians were very emphatic that scale should not be removed, but those countries were the only ones with that view. On the South Indian Railway, where girder bridges were subjected to heavy corrosion in the monsoon, steelwork was left unpainted for 12 months and then, after the season of heavy corrosion, the steelwork was scraped in the hope that all scale would be

removed. He doubted the efficacy of that method of removing scale. On the North Western Railway, at the other extreme of India, traversing a dry area as well as a very corrosive area near Karachi, scale was not removed, the girderwork being painted with a first coat of red lead and two subsequent coats of red oxide. In the dry region, the paint often lasted for 13 years or even longer, whilst in the neighbourhood of Karachi, where bridges were given one coat of red lead followed by second and third coats of red lead and fine slate graphite, the period between repainting was often only 6 months. Those figures compared with 5 to 6 years between repainting in Germany, where also scale was not removed.

Often, when an old structure had been cut up, he had heard people say "It is in splendid condition; the old mill scale is still on."

He thought the question of whether or not it paid to remove scale was still unanswered.

Mr. Hastilow had emphasized the importance of using a really good paint. At Karachi there was a railway bridge exposed to the full force of sand-laden monsoon winds. Every known brand of paint had been tried on the girders of that bridge, but none had survived the test. In the end it had been found more economical to use coal-tar varnish—a comparatively cheap paint—and to repaint the bridge every 6 months.

On the Great Western Railway, some of the wrought-iron girder bridges were nearly 100 years old, and corrosion was very slight compared with modern steel girder structures. If wrought-iron sections were more readily obtainable he thought engineers in Great Britain would prefer to build short-span bridges of wrought iron in preference to steel.

In New York State aluminium-alloy girders had been used in a new railway bridge. Pure aluminium had been introduced as an integral part of the sections, presumably on the surfaces. Did the Authors consider that an aluminium-alloy bridge would corrode less quickly than one of steel? The difficulty was that one had to wait such a long while for the results of corrosive tests. He would welcome details of how such weathering tests had been accelerated at Derby.

Finally, he would inquire whether high-tensile steel was more liable to rapid corrosion than mild steel.

Mr. R. L. McIlmoyle observed that he was not a paint technologist, but an engineer who had to use the results which the paint technologist produced.

He had been associated with Mr. Fancutt for more than a decade on the question of the protection of steel, particularly on bridges. That period, unfortunately, had included six years of war, when they did not make the progress which they had hoped; but the war years, with their accompanying problems of shortages of men and of material, had had a surprising result, in that they had enforced a new technique which had proved to be so satisfactory that the L.M.S. Railway was considering making it a standard procedure. Previously when a bridge required to be

painted the normal practice had been to clean the corroded parts, paint them, and then give the whole bridge—good, bad, and indifferent surfaces included—three or four coats of paint, so that over a period of time some parts of it would have had twenty coats of paint.

By doing that a substantial quantity of material was built up to protect the steel; but when the paint was not available it was necessary to do something else. What had been done was to develop the process of flame-cleaning the defective or corroded portions, and to treat only those portions with two or three coats of paint, as the case might be, whilst nothing at all was done to the other portions which were in good condition. As a result of the use of that technique, at the end of the war the Railway had almost no arrears of bridge maintenance, and the bridges were in substantially as good a condition as they probably would have been if all the material required had been available. It was now considered that that should form the basis of good peace-time practice—to treat the portions which were defective, and not to apply any paint to the portions which were in good condition, unless the weathering surface showed signs of failure, in which case another coat should be applied all over, to ensure protection of the basic inhibiting paint.

Flame-cleaning was more expensive than hand-cleaning, but was much more effective. It removed all the products of corrosion and provided a really good surface on which to apply the paint. That process had been used on the L.M.S. Railway for a sufficient time to enable something to be known about it. In the early days two panels were taken side by side on a bridge, one of which was hand-cleaned as well as possible and the other was flame-cleaned. Both were painted in exactly the same fashion. About $3\frac{1}{2}$ years later the hand-cleaned panel had broken down completely, whereas the flame-cleaned panel was as good as on the day when it was painted and, so far as could be seen, still had another three or four years' life left in it. That provided some indication of the result to be obtained from adequate prior treatment of the surface. Incidentally, it looked as though the Railway Company would obtain a 10-per cent. return on the actual expenditure on the flame-cleaning.

With regard to descaling, as apart from the flame-cleaning of corroded surfaces, the position was not quite so good. The film which the Authors had exhibited gave an idea of what had been tried, but it was much too early yet to say whether that was the answer. Mr. McIlmoyle doubted whether it was a complete answer; he thought that something still remained to be done. Before the war, however, the practice had been to give all steel one coat of red lead in the shops, followed after erection by three or four coats in the normal way. It had been found that after two or three years large portions of that paint had scaled off, leaving the steel bare again.

In order to overcome that difficulty, the method to which Mr. Berridge had referred had been adopted, except that the steel was not left bare but

was given one coat of shop paint and left to weather for about a year, whereafter the surface was cleaned and regular painting with four coats was carried out. But that had not been entirely satisfactory, and after the steel had weathered in the way described for 6 months flame-cleaning was applied, which brought a great deal of the scale off cleanly and gave a rather fine surface. Unfortunately, in the more sheltered portions of the bridge the red lead coat had protected the scale so thoroughly that it would not come off, with the result that it was left on certain portions, whilst other portions were clear of scale.

The practice had then been adopted of leaving the steel unpainted—allowing it to weather for three or four months and then flame-cleaning all over. Anyone who had seen the results would agree that the finished surface was all that could be desired; but the bridge had not been up for a sufficiently long time for it to be known whether the desired life would be obtained.

With regard to the protection of steel in general, and particularly in buildings, many engineers on altering or demolishing buildings had discovered, when the masonry had been removed, that a good part of the steel had disappeared. That was very common and was not confined to England alone; he had come across it in a number of other places. Mr. McIlmoyle considered that paint was of very little use in such a case. What had been done on the L.M.S. Railway was to clad all the structural steelwork with concrete and then apply the masonry. During the war, when formwork was difficult, the masonry had been built short of the steelwork by about 1 inch, or slightly more, and the space between the steel and the brickwork had been filled with liquid grout. Perhaps that was a poor substitute for complete encasement, but it seemed to give a satisfactory answer. But it was expensive, and if some other way of protecting the steel could be found it would be a tremendous help. He did not know whether manufacturers or the fabricators could develop some means whereby they could pickle structural steel in sections of large size and then phosphate it, but if something of that kind could be developed it would be well worth while.

Mr. F. M. Fuller observed that during the war the maintenance of bridges in the London area had naturally been reduced to the minimum, and owing to paint restrictions not very much was being done at present; but after the war he had decided to revise pre-war painting specification, which stipulated that a structure should be left unpainted until it was completed, then cleaned with wire brushes and scrapers, and finally given a red-lead priming coat and three coats of paint. Although that specification might be considered old-fashioned, it had given excellent results in the London area, where conditions might not be very severe. But after reading one or two pamphlets condemning that method of cleaning the surfaces and recommending pickling and shot-blasting, he had inquired of his suppliers what their reactions would be if in future he

specified pickling and shot-blasting for bridges. Without exception they had replied that it would be impossible for them to comply with the specification, as they had no pickling-bath large enough to take the parts, and no facilities for shot-blasting large members. Therefore he had issued several tenders recently with the old method of scraping and wire brushing.

The Authors had recommended flame descaling for maintenance, but Mr. Fuller considered that it was far more suitable for new structures than for maintaining old structures. He believed that when one side of a web plate was being descaled the other side became so warm that any paint on it was ruined. If that belief were wrong, his criticism would not be valid; but when dealing with a new structure it would be quite possible to descale both sides of a web plate and paint it afterwards, whereas on maintenance work, such as patching a structure, if descaling one side of a web plate which showed signs of corrosion caused the paint on the other side to be ruined, the quantity of painting required would be doubled, and also possibly the quantity of staging required, so that the maintenance costs would be increased very considerably.

It was necessary to judge spray painting in the public service to some extent on costs. In the public service it was very difficult to pass over the lowest tender. Recently tenderers had been permitted to quote for spray painting as an alternative to brush painting, and the brush painting came out cheaper. An idea existed that with the brush the paint was forced into the surface more than with the spray, and that therefore it lasted longer. The film exhibited by the Authors had shown that the first two coats, which presumably were the important coats, were applied by brush, and the last two by spray. Was that accidental or had the Authors more faith in brush painting than in spray painting?

To increase the life of the paint was of undoubted importance, but to double the life of the paint would not of necessity halve the maintenance costs. As the London County Council had found, much as they regretted it, that many structures included one or two awkward places through which water percolated and which were not visible unless examined from staging, the practice was to repaint bridges every five years so that those vulnerable spots could be cleaned and the priming coat on them could be renewed. However good the paint, Mr. Fuller would not like to leave any structure more than five years without a detailed examination.

Dr. J. E. O. Mayne suggested that the excellent results obtained with the iron oxide primer when applied to the ideal surface might have been due to the fact that the finishing coat contained white lead or zinc oxide. Exposure tests carried out some time ago by Dr. Hudson had indicated¹ that the protective value of white lead when used in a priming paint was comparable with that of red lead. Recent work at Cambridge University

¹ Rep. Corrosion Comm. Iron Steel Inst., vol. 4, (1936) p. 199.

had indicated that the protective action of lead paints was associated with the formation of soaps, and that those soaps were subsequently hydrolized, yielding water-soluble inhibiting materials. More recent work had suggested that zinc oxide functioned in a similar manner. Therefore it was possible that the soluble inhibiting materials derived from the white lead and the zinc oxide used in the finishing coat diffused through the iron oxide priming coat, thus preventing corrosion. The presence of rust or scale on the metal would provide an additional barrier and decrease the probability of protection.

Mr. F. M. Easton observed that, though the Authors had demonstrated that the best pre-treatment was complete removal of mill scale, it was not always easy to get that done in practical construction. Few structural engineering firms had the facilities for removing mill scale by pickling or sand-blasting; but with pressure it was possible to have it undertaken, and it had been carried on in connexion with some work on which he was employed in the design and construction of dock gates. The same principles applied more or less to descaling bridge-work.

The type of descaling which he had in mind was the Admiralty practice of pickling in a 5-per cent. solution of hydrochloric acid. It had been the Admiralty practice thirty years ago, and he believed it still was, to pickle plates and angles and carry out the final painting perhaps twelve months after erection. On the dock gates with which he had been associated the need for complete removal had been realized twenty years ago; therefore the steel had been pickled, the erection effected under cover if possible, but more often in the open, and the final painting carried out from 6 to 11 months after final erection: during the war the period had been two years. Some rust formation occurred if the steel were painted six months after descaling, and very considerable rusting if the painting were carried out two years after descaling. Did the Author consider that the initial effort in removing the mill scale would be entirely offset by that long period of weathering? **Mr. Easton** did not think so; he believed that it was in any case preferable to remove the mill scale.

What would happen if it were decided to have the plating painted directly after it had been pickled? That could be done; a priming coat of red lead paint could be applied. If the plating had to be drilled and riveted not much difficulty would arise so far as construction was concerned, but if it was to be electrically welded trouble might be caused owing to the adhesion of the paint where the welding was effected. What should be the preliminary protective coating following the descaling if the final coating was to be of bituminous enamel? He assumed that it should be a coat of bituminous solution, and if that were so, how would it affect subsequent welding? His question was really: having persuaded the structural steel firms to put down pickling plant, would it be practicable, in welded construction, to apply a protective coating immediately after descaling?

With regard to the tests on hot-applied tar described on p. 16, *ante*, 0.2 ounce per square foot worked out at 98 square yards per gallon of tar, but the kind of tar of which he had experience—dehydrated horizontal retort tar (applied, it was true, over red lead paint)—worked out at $12\frac{1}{4}$ square yards per gallon, or about one-eighth the covering power, so that the practical, everyday thickness of tar would be about eight times that used in the test. Therefore any results deduced from the tests could hardly be comparable with the kind of protection given in practice. Perhaps the temperature of application in the test had been higher than when the tar was applied at the works.

Mr. R. E. Shaw observed that he had specialized in the study of pre-treatment for many years and could strongly support the Authors' statement that pre-treatment helped considerably to lengthen the life of paint coatings. One aspect which had not received much consideration in the discussion was the influence of the design of structures and that was important if the maximum benefit were to be derived from pre-treatment and paint. Weak spots in structures were always likely to occur unless that point received prior consideration.

If the Authors' assertion that red-lead paint was preferable to red-oxide paint where the conditions were not ideal was applicable when the latter paint was of good quality, it was even more true for the poor quality of red-oxide paints which were often encountered in industry, since red-lead paints were generally of a better quality than red-oxide paints.

The Paper indicated that tar could form quite a good protective finish, at all events in relation to the thickness of film. One advantage of tar or bituminous compositions was that they could be applied in very thick coatings, particularly by hot-spraying.

With regard to competition between metal spraying and painting, he did not share Mr. Hastilow's jocular pessimism about the future of the paint industry. Sprayed metal coatings formed a very good base for paint and might really be regarded as very effective pre-treatments.

Mr. O. J. Masterman observed that he wished to ask a question in connexion with the protection of light metal sections for prefabricated housing. The methods of protection which had been discussed showed that great economy might be realized in important structures exposed to the atmosphere, but there was another and quite a different problem in prefabricated housing, where steelwork of very light section was not exposed to the weather at all, but was inside the house.

The Ministry required permanent housing to be designed for a life of at least 60 years, and great ingenuity had been used by a number of designers recently to reduce the size and weight of metal in the framing of the house; but they had come up against the unfortunate result that although they might halve the weight of steel in the framing of the floors, they might in the end double the cost of that framing, simply because in getting down to a very light-gauge steel they were required to spend a

great deal more on protective treatment. In particular, if the framing were reduced below $\frac{1}{4}$ inch in thickness the metal would have to be phosphated before painting, whereas if a hot rolled section of more than $\frac{3}{16}$ inch were used that might not be necessary.

In the case of the very thin sections of steelwork now being used for permanent housing, if a phosphating treatment were applied and then, say, two good coats of paint, what would be the probable life? It was almost certain that some of those steel sections could not be maintained; unless the house were pulled to pieces they would not be seen again, and they could not have regular coats of paint applied to them at intervals.

* * **Mr. Duncan Bailey** observed that it appeared obvious that the country had at last awakened to the necessity of designing and building steel mineral-wagons as opposed to wooden wagons, a policy which he had advocated for at least 20 years. Recently the Minister of Transport had stated that no fewer than 70,000 16-ton steel wagons were to be built, and large numbers had been and were being built.

In the early days, opposition to their introduction was generally based upon the vexed question of corrosion, especially as washed coal came more and more into use.

In 1890 Mr. Bailey had seen some of the very first steel underframe coal wagons built in Birmingham, and he had lived to see that the mistake then made was the fixing of wooden floors on the steel underframes. Examples of those wagons in his firm's works clearly demonstrated the trouble due to those wooden floors.

Until some steel or some method of protection for the floor-plates and the lower portions of the body-plates in steel coal-wagons could be found (provided that the underframes and the running gear which constituted two-thirds of the cost of the wagon could be protected) it would be possible quickly to remove the bodies and replace the floors and the lower portions of the body-plates. Mr. Bailey's experience was that that was generally found to be necessary in a period ranging from 10 to 15 years after the wagon had been built; but, even then, the saving in the use of those vehicles, in comparison with standard wooden wagons, was very considerable; moreover, if the coal traffic of the country could be carried in wagons of that type, instead of in the existing standard 12-ton wooden stock, about 20 million tons of dead-weight haulage per annum could be saved in the coal traffic on the British railways. Those wagons could not be built in five minutes, but a move was already being made in that desirable direction.

He had no doubt that, in due course, quality of steel and some form of protection would be found which would prolong the life of the plates in steel coal-wagons.

Formerly, with a desire to minimize the weight of the wagon, the body-

* * * This and the following contributions were submitted in writing.—SEC. I.C.E.

plates were made $\frac{3}{16}$ inch thick, but about fifteen years ago he concluded (after discussing the matter with the late Sir Nigel Gresley) that such plates were too thin and therefore he substituted plates $\frac{1}{4}$ inch thick, which was the present standard; that showed that, whilst reducing the dead-weight wherever possible, sight should not be lost of the strength required to withstand rough treatment during shunting operations and to increase the resistance to corrosion and abrasion.

With a desire to collect data regarding corrosion in steel wagons under actual traffic conditions, Mr. Bailey, in the ten years commencing 1926, had several wagons built, using the following different brands of steel and incorporating them in the members of the same underframe, so that there would be no question as to the conditions under which the different steels had been at work :—

Ordinary mild steel.	"Chromador" steel.
Grade "B" iron.	"Edrow" steel.
"Kuplus" steel.	"Armco" iron.
Copper-bearing steel.	

Those vehicles were still in traffic. Before the war, they were returned to the works for periodical examination, but upon requisitioning sight of them had been lost for the time being. However, they would doubtless be found and examined some time in the future. They should provide very valuable information as to the behaviour of the different types of steel used in their construction. The periodical examinations made before the war had disclosed no appreciable difference between the materials, and therefore Mr. Bailey had concluded that, taking all things into consideration, ordinary commercial mild steel of 28–32 tons per square inch tensile strength might be regarded as satisfactory for the construction of such vehicles, at least until something more advantageous was developed.

Mr. W. E. Ballard observed that, in his view, paint and metallic coatings were in no way competitive, but were complementary one to the other.

He had been responsible for the development of metal spraying in Great Britain, and he had been conscious of some resistance to the idea from paint manufacturers. On the other hand, he was sure that those interested in the production of metallic coatings had always been careful to suggest the use of the best paint possible on the metal surfaces. It was now well established that for maximum protection both coatings were needed if, as was usually important, the structure had to be painted in order to present a satisfactory appearance.

During the discussion it had been asserted that fabricators of structural steelwork were not in a position to clean the surfaces of the articles they produced, by either pickling or grit blasting. Mr. Ballard considered that that was only a question of the demand from the designing engineer for such cleaning, as it was by no means impossible to clean the largest

of structures by means of grit or sand blasting. There could be no doubt that that was a very positive way of cleaning, as it removed all scale and was therefore even more satisfactory than flame-cleaning.

His experience has been that there was not much difference in cost between grit blasting and flame-cleaning, but grit blasting had the advantage that it provided a surface which could be used for the reception of metal-sprayed coatings, whereas flame-cleaning did not.

In dealing with large structures, obviously the question of cost was important, and some engineers had the impression that a metallic coating was too costly. Mr. Ballard believed that if they would examine the question thoroughly by obtaining quotations they would find that the cost of grit blasting and spraying with aluminium was not very different from the cost of flame-cleaning plus several coatings of really good paint applied in the correct manner. Any difference in cost would, after a few years, be entirely balanced by the metallic undercoat and the lower costs of maintenance.

Mr. E. J. Bond observed that the emphasis laid by both Authors upon the paramount importance of the factors of proper design, pre-treatment of surface, and conditions of application to ensure a thoroughly sound and serviceable protective coating of paint was encouraging to those whose business it was to manufacture paints for the protection of iron and steel structures. The Paper had reiterated and expanded much information which had been available for many years, and it was obvious that existing knowledge, if correctly applied, would markedly reduce or frequently eliminate troubles and often serious losses arising from corrosion. All too frequently, and usually unfairly, serious and premature corrosion of a painted iron or steel structure was ascribed to bad paint or bad painting practice. Whilst no surface pre-treatment could be universally applicable, the variety of methods existing should ensure that no ferrous materials were painted in an unsuitable condition.

It had been proved again that proper surface pre-treatment and attention to application methods could prolong the life of initial paintwork by two or three times; further, it could be stated that, provided repainting was carried out at proper intervals, no deterioration due to corrosion would occur. The excellent condition of certain painted iron structures—some of which were 100 years old—showed that complete protection against atmospheric corrosion could be obtained by means of paint.

In Mr. Bond's experience the single most important cause of premature failure of exterior paintwork on iron and steel was the practice of painting partly rusted, partly scale-covered surfaces in the condition described as "as rolled." That condition was worsened by the inevitable delay between manufacture and painting, resulting in the rusted and scaled conditions occurring together. Table IV recorded two series of tests on specimens painted in the "as rolled" condition. In one case 100 per cent. and in the other 92 per cent. failure occurred. Unfortunately,

almost as high a percentage of steelwork was painted in the "as rolled" condition. The practice of applying at the rolling-mill a "shop coat" direct to the unscaled surface resulted in considerable improvement, both in practice and as shown by the results of the tests recorded. By comparison with results obtained by proper pickling procedure, followed by drying and immediate painting, it was evident that the practice of applying a "shop coat" on unscaled metal could be improved. Therefore it was surprising that purchasers of steelwork did not insist upon proper pickling and shop coating at the mills before delivery to a site. Usually it was impossible to carry out pickling procedure on site, and therefore the operation was best performed by, and under the control of, the steel manufacturer, who should consider the operation as part of his process. The extra expense involved would be of little account in comparison with the cost and trouble occasioned by premature paint failure. Presupposing that on "as rolled" steel repainting became necessary in half the time required with pickled shop coated steel, the cost of repainting, at present-day levels for labour and materials and neglecting considerations of scarcity, would turn the first expense into a real economy.

The Authors had not emphasized the difficulties, cost, and generally poor results of attempting to make a sound painting job on a defective and corroded structure. The phrase usually included in specifications—"Remove old paint, loosely adhering rust and scale by chipping and wire brush"—did not convey the difficult and slow nature of that operation unless one had attempted to do it personally. It was unlikely that a structure in a highly corroded state could ever be brought into satisfactory condition for permanent painting at a commercially possible cost. Flame-cleaning was a great advance on the usual scaling and wire-brushing methods, but it was costly and would be unnecessary provided the original painting was carried out in accordance with the principles indicated, and that correct maintenance periods were observed between repaints.

Dr. U. R. Evans observed that the Authors' main contentions were supported not only by their own exposure tests, but also by general service experience. A comparison of their conclusions with those reached in the exposure tests organized from Cambridge, conducted on some thousands of smaller specimens covering a considerable range of conditions, showed very general agreement.

He could support the statement that the pre-eminence of zinc coatings "will shortly be seriously challenged by aluminium." Some tests carried out on roofs in London¹ showed that for seven years a coating of sprayed aluminium had prevented all rusting of the steel, whilst the aluminium coats, although showing some blistering and disintegration, were by no means destroyed; on certain specimens, where the zinc coat had been applied outside the aluminium coat, the zinc had largely disappeared.

¹ S. C. Britton and U. R. Evans, *J. Soc. Chem. Ind.*, vol. 58, (1939) p. 90.

Where a single coating of cheap iron oxide paint had been applied outside the aluminium coat, the aluminium remained in perfect condition, and the paint coat had suffered no change, apart from darkening by soot. Analogous tests carried out in soot-free atmospheres showed that the paint kept its colour far better when applied upon a coating of aluminium than when applied direct to steel. The darkening in such situations appeared to be due to the outward diffusion through the paint of iron salts which were precipitated as a dark form of iron oxide at the surface. Paint coats applied to a stainless steel also kept their bright colour unchanged.

The statement that, on a steel surface painted in the "ideal condition" a red lead primer behaved less well than an iron oxide primer, appeared, at first sight, to conflict with the results of the paint tests organized from Cambridge, which suggested that red lead was the better primer of the two. The discrepancy might be attributed to the fact that in the Cambridge tests the steel was not always in the ideal condition, since the surface was generally cleaned by grinding, and a special series showed that a ground surface behaved rather less well than a sand-blasted or pickled surface. More probably the difference lay in the pigments. The Authors had mixed aluminium with iron oxide, whilst their red lead may have contained less monoxide than that employed in the main Cambridge tests. It was found, in the Cambridge seven-year series, that red lead to which litharge had been intentionally added consistently behaved better than red lead relatively free from monoxide. Doubtless that was due to the presence of lead soap, which, as shown by Mayne,¹ constituted the true inhibitor. The use of red lead containing added litharge entailed the practical disadvantage that it had to be applied immediately after mixing; whether from the engineering point of view that disadvantage would not be out-balanced by the fact that such mixture might increase the period which could be allowed to elapse between repaintings, was a question deserving serious consideration.

The general conclusion that, for the best results, rust and mill-scale should be removed before painting, was in full agreement with the Cambridge tests and with practical experience throughout the world. In one case known to Dr. Evans, power poles descaled by pickling before painting had retained their outside mill-scale. The question as to whether descaling should be carried out at the works or at the site might be important. Pickling at or near the site of erection of a structure might often present practical difficulties, although in the case just mentioned those were overcome; shot blasting, however, could be carried out almost anywhere. No general answer to that question could be given; the decision would have to depend on circumstances.

Where large quantities of structural steel had to be treated, the expense of removing scale and rust before painting should not be very great. For

¹ J. E. O. Mayne, *J. Soc. Chem. Ind.*, vol. 65 (1946), p. 196.

small and scattered jobs, however, cleaning by thorough descaling might be impracticable. Thus it could not be asserted that the problem of protection had been solved until a paint became available which would provide good protection to steel still carrying scale broken up by rust patches. Some special tests carried out by Lewis and Dr. Evans¹ indicated that the worst possible condition for painting steel was after exposure to the weather for just such a time that *small* islands of rust were produced, surrounded by *large* areas of scale; that was an example of the principle that a combination of small anode and large cathode led to the most intense attack. Since there were many kinds of scale and many kinds of rust, generalization would be unwise; but it was certain that a combination of mill scale broken up by small patches of rust involved danger, and it was just that condition which the engineer was most likely to meet with in practice. A completely rusted surface would rarely arise, except where steel, after being descaled, had been left exposed to the atmosphere before painting—an occurrence which should be avoided.

It happened that the paints richly pigmented with metallic zinc were particularly suitable for protecting a surface of mill scale broken up by small rust patches, since the lateral conductivity of the zinc coat should provide anodic protection at the centre of the rust patches. Therefore they might offer the solution of the problem. The Authors' kind reference to the work at Cambridge on the zinc-rich polystyrene paints was much appreciated.

Two queries had, however, arisen in regard to zinc-rich polystyrene paints. The first concerned keeping-power in the pot, which in some of the early samples was variable, owing to war-time variations of the raw materials; Dr. Evans believed that those difficulties had been overcome. The second concerned adhesion—a matter to which Mr. Fancutt had referred. It was believed that, provided adequate time were left for hardening, the physical adhesion was no worse than that of other paints: since the polystyrene paints dried more quickly than oil paints, there should be no difficulty in allowing the necessary period for hardening. On the other hand, zinc-rich paint coats applied to steel which was exposed in certain environments (for example, in salt water) might become loose through chemical causes. The cathodic products of the cell zinc/iron included alkali and hydrogen, and those might be produced at the junction of the zinc coat and the steel basis. The creeping power and loosening action of alkali was well known, whilst hydrogen, if liberated as gas, might help to push away the coat. If the alkali were produced locally at specific cathodic spots on the steel, it might draw in water by osmosis, and the coating, previously loosened, would be pressed out as blisters. Where the production of alkali was more uniform, flaking or diminished adhesion might be more general. It was believed that the causes of the

¹ K. G. Lewis and U. R. Evans, 3rd Rep. of the Iron and Steel Inst. Corrosion Comm., 1935.

various types of loosening were understood, and scientific work was in progress for the elimination of the trouble, although complete success had not yet been obtained.

The electrochemical mechanism of the detachment of zinc-rich polystyrene paints, met with in certain situations, was suggested by Simnad's recent fatigue tests.¹ When steel specimens coated with zinc-rich paints were subjected to alternating stresses under dry conditions, there was no tendency for the paint to crack or flake off, which suggested that the *physical* adhesion was good. When the experiments were repeated under a stream of sea-water flaking occurred, which was attributed to the electro-chemical action suggested above; it was hoped that the trouble would be overcome.

Actual blistering seemed to occur only in sea-water. Mayne's experiments in zinc-rich paints applied to steel carrying scale broken up by small rust patches indicated satisfactory protection towards an inland atmosphere. Nothing had come to notice which would suggest that the adhesion was unsatisfactory under atmospheric conditions; but if Mr. Fancutt had new evidence pointing to poor adhesion in such environments, information would be appreciated, so that the trouble could be studied and corrected.

Mr. W. A. D. Forbes observed that the present need to conserve supplies of linseed oil made it imperative to use the available supplies to produce high-quality paints with a long life. Such paints were apt to be more costly, but were well worth while in the long run, provided that the conditions under which they were applied were such that they were enabled to function in such a way that their good qualities could be utilized. That meant that the surface to which they were applied should be first brought to a condition in which it was clean and free from rust and scale. That cost money, but unless it were done there was little use in paying for good-quality paint, and breakdowns of the paint system would soon occur, necessitating early repainting and more costly maintenance.

In the shipbuilding industry the conditions under which painting was generally carried out were, on the whole, exceedingly bad and it was surprising that shipowners and shipbuilders were apparently so ill-informed as not to be aware that improvements were possible. The Paper would have served a very useful purpose if it helped to dispel the ignorance which prevailed in those matters. In naval circles comment had often been made on the superior finish of the warships of the U.S. navy in comparison with those of the British navy. A major reason for that state of affairs was that in the U.S. navy all the plating used was pickled on receipt into the shipyard, and was immediately painted with a priming paint. British shipyards were not equipped with the plant necessary to do that, and it would be a great convenience, not only to the shipbuilding industry but also to all users of structural steelwork, if the steelmakers would undertake that service as a necessary part of the steel manufacturing

¹ M. Tchouabdj-Simnad and U. R. Evans, unpublished work.

process. Until that first step was taken little was likely to be done to improve the painting procedure of large structures, in view of the many difficulties which faced those whose business it was to seek to cut down maintenance costs, and Mr. Forbes hoped that the Paper would help to secure recognition of the need to extend pickling facilities and the practice of pickling.

The increasing use of flame-cleaning was interesting, because it was certainly very advantageous to apply paint to a surface which was dry and warm. An alternative method for cleaning surfaces which had not been mentioned by the Authors was that known as the wet sandblasting process, in which a chemical solution was used to wet the sand used for cleaning, leaving the surface in a bright passivated condition for a period ranging up to 24 hours according to weather conditions. The wet sandblasting process was widely used in U.S. naval shipyards. An account of the method had been given in a Paper dealing with "Underwater Paints and Fouling of Ships" presented at the 1946 Spring meeting of the Institution of Naval Architects. Probably the ideal preparation of rusty steel surfaces prior to painting would be a combination of wet sandblasting and heating by the flame-cleaning type of heater; but it was also probable that at present commercial considerations would rule that out of court in many cases, as it would be difficult to convince those concerned with the financial side that the cost was really worth while. Mr. Forbes hoped that the information given by the Authors might make it appear less fantastic to spend large sums on pre-treatment, which was the essential step to the realization that it might after all be good business to spend even large amounts initially in order that maintenance cost might be reduced in the long run.

The co-operation now established between the Corrosion Committee and the paint industry should be of great benefit to all concerned, and might ultimately lead to the drawing up of codes of good practice for painting which would provide authoritative guidance to all users of paint.

Dr. S. A. Main observed that design was certainly a factor in promoting or retarding corrosion. Rain drained away from vertical members after a shower, whilst horizontal members remained moist by the retention of a film and droplets.

A good example was presented in Westminster, where a modern building with horizontal railings more according to present-day fashion had been built next door to an older building with the orthodox vertical railings. Incidentally, the rather disreputable and contrasting appearance of the newer railings had led to repetition of the common fallacy, which steel makers so often had to rebut, that steel was not so good as in the old days.

With regard to wooden floors on steel, did the Authors attribute the excessive corrosion in any major degree to corrosive constituents deriving from the wood? Many engineers had that idea, in cases where explanation

by what was known as "shielding corrosion" seemed to Dr. Main to be adequate.

Mr. R. St. J. Preston observed that the Paper, representing the accumulated practical experience of two leading specialists in the field, should be of great value to structural engineers.

He wished to emphasize the importance of treating steel at the earliest practical stage of its manufacture. In the case of iron the spreading of tar, linseed oil, graphited linseed oil, or red lead over its surface while hot had been found many years ago¹ to be an effective insurance against rust; Mr. Preston considered that the application of such methods to steel should be advocated where subsequent operations did not rule out their use. Protective treatments of steel were influenced considerably by present economic difficulties—plant, material, and labour shortages—and those would play a part for some years in influencing the choice of protective methods.

In some cases protective treatments might cost more than the steel itself; that was particularly true in the case of thin sheet steel, and the cost could be easily justified. It might be argued that as a 20-gauge steel sheet would be rusted through within 10 years in an industrial atmosphere, a sheet six times as thick would be required for a 60-years' life (the expectation of life of prefabricated permanent dwellings). Consequently an expenditure of anything less than five times the cost of the steel on a protective coating that would last 60 years would be justified. (The figures given were merely examples and were not intended to be precise.)

Many protective systems were available that should ensure freedom from serious corrosion for that period, in an average type of atmosphere. Two general types were indicated: (a) those that provided long-term protection with little maintenance and (b) those that were renewable. The Authors had dealt with both of those types, but Mr. Preston suggested that, as thickness was an important factor in the durability of protectives falling in the first group (largely metal coatings), the ratio of the cost of equal volumes of such metals should be considered (among other factors) when making a selection. Compared with steel, the ratios of the volume costs of common coatings were approximately:

Steel	Al	Zn	Pb	Cu	Ni	Sn	Cr	Cd
1	1½	3-4	6-7	7-8	13	20	24	70

(Note. Steel based on cost of sheet, other metals on bulk prices in the current issue of "Metal Industry.")

On that comparative basis (which was only one method of appraisement) aluminium was in a highly favourable position relative to other coating metals. Its corrosion resistance was also high, and the Authors' view that

¹ S. Rinman, 1814, quoted by Deeves, *Trans. Electrochem. Soc.*, vol. 64, 1933, 106.

it might rank with zinc as a common protective for steel was doubtless justified.

In the special case of tar paint referred to on p. 16, the spread of tar (0.2 oz. per square foot) represented nearly 100 square yards per gallon—a thin coating for a protective paint. The comparative value of different protective systems should be assessed from their annual cost over a period of years. In the simplest case,¹ denoting labour costs of painting by L and material costs by P for a life of n years, the annual cost = $\frac{L + P}{n}$.

That formula might be used to assess the value of a variety of protective systems. For example, if the tar and paint coatings mentioned in the Paper, having lives of approximately $2\frac{1}{2}$ to 5 years, were compared by means of that formula, the tar would be found to be roughly as valuable as the oil paint.

Comparisons should strictly be made on appropriate formulations in each case; thus a pigmented oil paint should be compared with a pigmented tar mixture spread at equivalent rates. In the case of tar (and similar bituminous materials) 1 gallon, covering 25–30 square yards, should afford an economical and satisfactory protective coating, provided that the tar were of a quality as good as that exemplified in the Paper.

Mr. C. H. Stanger observed that the test results given by Dr. Hudson indicated that tar painting failed to provide adequate protection for structural steelwork. The film weight used in those tests corresponded with a film thickness of 0.014 inch. Mr. Stanger wished to draw attention to that, because the use of hot applied tar-pitch mixtures, particularly when used over carefully prepared surfaces primed with red lead, could provide protection for inaccessible surfaces over very long periods. It was essential, however, that the film thickness should be of the order of 0.1 inch. The addition of lime and tallow was unnecessary, but coal-tar pitch should be added to the tar in order to prevent flow under the prevailing conditions. Hot applications of that type presented many manipulative difficulties, but the modern technique developed for the application of bituminous hot enamels was quite suitable.

Dr. W. H. J. Vernon observed that the importance attached, in Part I of the Paper, to the influence of design of structures was very opportune; many examples had come to notice at the Chemical Research Laboratory, Teddington, in which failure could have been avoided by more careful attention to that factor—which was of wider significance than was commonly supposed. Striking examples of the corrosion of steel (and other metals) through contact with wood had been described in 1944² by Campbell and Packman, of the Forest Products Research Laboratory, together with measures for avoiding that trouble.

Cf. A. H. D. Markwick, "Protective Paints" (Instn Civ. Engrs, S.E.P. No. 59, 1928).

² "Wood as a Causal Factor in the Corrosion of Metals." *Wood*, May, 1944.

Dr. Vernon could endorse the Authors' remarks concerning the solubility of zinc coatings in highly polluted atmospheres ; but under less drastic conditions, and particularly under conditions of salt spray, a zinc coating of moderate thickness was able to build up a remarkably tenacious corrosion-resistant product.

He also concurred in the Authors' insistence on the importance of methods of pre-treatment ; frequently the conditions of the interface were of greater significance than the intrinsic properties of either the metal or the coating. Since the desirability of complete removal of rust and scale was generally agreed, special interest attached to the comparison of different methods of effecting such removal. In that connexion, he considered that the usefulness of the results given in Table IV would have been increased if the number of specimens used for each treatment had been more nearly uniform. Thus, treatment with 5-per cent. sulphuric acid (80°) containing inhibitor had given a 100-per cent. yield of "good" specimens, in comparison with a 20-per cent. yield for acid of the same concentration and temperature without inhibitor ; on the other hand, the numbers of specimens used in the tests were respectively four and seventy. Possibly the improvement resulting from the use of inhibitors might be due in some cases entirely to the prevention of rusting prior to painting ; in other cases a film might be produced which would contribute directly to the improved adhesion. (N. F. Miller¹ had shown that chromate treatment to prevent rusting did not sensibly alter the wetting properties of the steel, which, it was believed, were associated with the adhesion factor.) Clearly there was room for much further work in that direction.

The Authors had considerably clarified the position concerning the extent to which rust (as distinct from scale) affected the adhesion of the coating. They had not, however, referred specifically to the effect of brushing ; for example, in the tests recorded in Table VII, had the rusted specimens been brushed? If not, to what extent would the results have been affected by a light brushing to remove loose rust, as distinct from that which needed more drastic treatment for its removal ?

The advantages of flame-cleaning, particularly in maintenance work, which had been so clearly brought out in the Paper, inevitably revived the old question of applying paint to hot surfaces as soon as possible after fabrication. There could be no doubt that, as stated by the Authors, "the initial treatment is the most important."

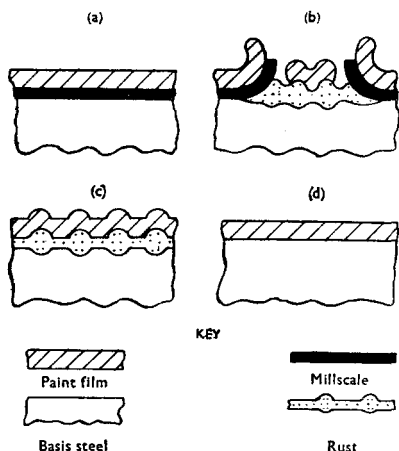
Mr. J. D. Zimmerman observed that some years ago he had had to construct a small under-carriage for an apparatus subjected to constant heating and therefore to rapid corrosion. The apparatus was to be used either in the workshop or out of doors and had to withstand all degrees of atmospheric conditions.

In order to prevent the occurrence of corrosion, he had experimented

¹ *J. Phys. Chem.*, vol. 50, (1946), p. 300.

by copper-plating the structure by means of a high-speed revolving copper brush driven by an electric motor. The structure was not dipped in an electro-plating solution in the normal way, but, instead, a coat of copper was deposited upon the surface as a result of the abrasive action of the tips of the copper bristles. Thus, a cleaning and plating action was combined in a single operation. The experiment proved to be successful; moreover, a considerable improvement in the architectural appearance of the job was achieved.

Figs. 13.



- (a) Paint over intact millscale:— this might give a good result under some conditions but these cannot be realized industrially.
- (b) Paint over broken millscale and rust:— this leads to rapid failure.
- (c) Paint over rust without millscale:— pinhead blisters develop and are a source of weakness in the paint film.
- (d) Paint over a descaled rust-free surface:— the ideal surface condition. Failure can only occur slowly as a result of breakdown of the paint-film from without.

EFFECT OF SURFACE CONDITION ON PAINT PERFORMANCE SHOWN DIAGRAMMATICALLY.

the mill it carried with it mill scale, the thickness, constitution, and properties of which varied enormously with the section and the conditions of rolling, and from one works to another. Any structural work of any magnitude would include a heterogeneous mass of all kinds of steel sections, with mill scales of many different types; and therefore, whilst the view that a good result might be obtained by applying paint over perfectly intact mill scale was correct in some cases, it would be impossible to carry out that procedure under practical conditions in the case of a large structure, where the building and assembly might take months or even years.

The same method was used for obtaining a priming coat for soldering cast-iron. In that case the result was so successful that Mr. Zimmerman had employed the same means for soldering a broken vice, which was subsequently subjected to hammering. So far as he knew, the vice was still in use.

Had any research been undertaken into that form of treatment, and had anything been published on the subject? In his experience, the method had proved to be both durable and cheap, and it was also capable of application to small structures by unskilled labour.

The Authors, in reply, expressed their appreciation of the kind remarks made about their work, which they hoped would prove of value. They were glad to find that the views expressed in the Paper had met with such unanimous support.

Figs. 13 would give a rough conception of how failure of a paint film occurred on structural steel. In the ordinary state in which the steel left

The best thing to do, therefore, was to get rid of the mill scale. That could be accomplished by the recognized methods of descaling, of which pickling and grit blasting were two good examples. If paint were applied over a properly descaled surface the protection would fail by disintegration of the paint film itself. That type of protective treatment would have a life of the order of 10 years or more. The Authors could produce specimens prepared on a laboratory scale in that way which had had such a life.

What usually happened in the normal weathering process was that finally paint was applied over a mixture of mill scale and rust. Apart from the fact that mill scale was cathodic to the steel base, and therefore there was a danger of electro-chemical action, the mill scale undoubtedly constituted a source of weakness, and there was undermining of the mill scale by the atmospheric influences, so that the whole paint film was disrupted in a comparatively short time. That danger was particularly pronounced in the case of the dock gates mentioned by Mr. Easton, where pickling or descaling was absolutely essential; it was not so pronounced in the case of atmospheric corrosion. The life of such a paint system on heavy structural steelwork might be assessed at one year. It would depend very much upon the thickness of the section, because the lighter the section the thinner would be the mill scale and, in general, the more resistant to atmospheric attack. It was impossible to generalize; but with heavy structural steel of $\frac{3}{8}$ -inch web thickness or more, unless the cleaning had been extremely thorough, the life of an ordinary painting scheme would be of the order of one or two years.

Another state of affairs was where all the mill scale had been removed, either by natural weathering or descaling the plate, and where the plate had been allowed to rust before applying the paint. In other words, a paint film was being applied over a rusty surface. No amount of mechanical cleaning and hand-brushing, regardless of expense, time, and labour, would remove all that rust from the steel; a certain quantity would always be left in the pores. The roughness of a steel surface of that kind would be of the order of 0.002-0.003 inch in any case, and the brush would not penetrate it.

What happened in a case of that kind was that fine blistering occurred to a degree which depended upon the quantity of rust left underneath the paint film. That was probably due to the fact that the rust was not chemically stable, and that a certain degree of swelling, possibly of a colloidal nature, would occur under the paint film. When a paint film was applied over a rusty surface without any mill scale that blistering always occurred; it might or might not result in failure of the paint film, but it was always a source of weakness. It would be impossible to assess the life in that case, but it would always be less than the life obtained with a properly descaled surface.

The question then arose of how far that pin-point blistering could be remedied by flame-cleaning. The final answer was uncertain, because the

flame-cleaning process had not been in operation for very long, but it could be stated that, although that process reduced the tendency to blistering, presumably by dehydrating the rust, it did not eliminate it altogether. It would not be possible to state whether the residual blistering was of any practical importance until more practical and experimental experience had been gained; but the fact was that the flame-cleaning process did not entirely abolish the possible influence of the rust which remained on the surface. Therefore it was doubtful whether the flame-cleaning process would ever be quite so good as the descaling process properly conducted under good conditions and followed by immediate painting.

With regard to the relative durability increase due to phosphating, the Authors' experiments had not been in progress for a sufficient length of time to enable definite figures to be given. The main advantage of phosphating and similar processes was that they offered a reliable and perfectly safe method of treating, in particular, light-gauge steel in the processes of mass production.

In reply to Mr. Berridge, a bridge in high-tensile steel would, on the whole, be expected to have a longer life than one in ordinary mild steel, quite apart from any protective coating, because most of the elements that were added to steel to produce its high-tensile qualities (unless it were a straight carbon steel) also tended to increase its corrosion resistance. That applied particularly to such elements as nickel, chromium, and copper.

In reply to Mr. Easton, within reason it was practicable to descale and paint structural steel on a large scale. The practice of a firm in the North of England, who were interested in constructing gas-holders, was to pickle and prime at their works plates of fairly large size (about 14 feet in length), and there was no reason why the process should not be extended to other sections and to even larger plates. The Authors hoped that in due course such facilities would be more readily available within the iron and steel industry and the constructional industry than they were at present.

The Authors believed that the figures given in the Paper with regard to the hot-applied tar were correct. The tendency in conducting work on a small scale was for the paint or coating to be brushed out far more thinly than occurred in practice. That was one of the few bones of contention which they had with their friends in the paint industry from time to time when discussing the practical interpretation of their experimental results.

In reply to Mr. Donovan Lee's query with regard to Table V, the main point regarding the two paint systems used appeared to have been lost sight of. In one case red oxide primer had been used, which it was safe to say had little or no inhibiting value. In the other case red lead primer had been used, which had a very high inhibiting value. Where surface preparation was adequately carried out a non-inhibitive paint such as a red oxide paint behaved quite well, but when rusting was allowed to occur

before the application of the priming coats of paint the red-lead primer began to exert its influence and showed up to advantage.

From Table V it would be seen that the panels coated with paint processes G and H were in serviceable condition at the end of the full period. The explanation of the relatively small number of failures after 48 months' exposure was that the great majority of the specimens were in a good surface condition at the time of painting.

With regard to red oxide and white-lead finishing paint, the suggestion that the soluble lead compounds in the finishing coats might have permeated through to the priming coat was feasible, but the Authors did not regard it as the complete answer, although they were ready to subscribe to the view expressed as to the inhibiting action of lead soaps; ample evidence was available from tests now in progress that that was fully substantiated.

Both Mr. Lee and Mr. Berridge had referred to the use of aluminium-coated sheets and aluminium-alloy structural members. The latter subject was outside the field under discussion, but there could be no doubt of the value of aluminium coatings as a protection for mild steel and in all probability it was merely a question of time before the use of aluminium-clad steel sheets became much more general.

The Authors could not imagine that any maintenance engineer in Great Britain would be satisfied with the general conditions of maintenance painting on the Indian railways, as described by Mr. Berridge. A great deal of patch painting was done which never appeared in the regular schedules, and the conditions of painting were so widely different from painting practices in Great Britain that perhaps it was unwise to make a comparison.

The cleaning by the flame-cleaning method of panels which had been painted on the reverse side was not done; both sides were cleaned before any painting was carried out. The system of accelerated weathering which had been built up over a period of about 15 years in the Paint Research Laboratory of the L.M.S. Railway, Derby, involved exposure to radiation from carbon-arc lamps plus water-spray. Other cycles embodying refrigeration had been tried, but had been discarded. For general purposes, on paint required for the protection of steel, the cycle embodied exposure to ultra-violet light plus water-spray and then exposure in a series of cabinets to steam and controlled atmospheres of SO_2 . It had been found that that cycle gave definite correlation with service conditions, as demonstrated in Part II of the Paper.

Mr. Hastilow had made a useful contribution in pointing out the scarcity of raw materials for the production of protective paints, which rendered it of paramount importance under present conditions to ensure that the maximum service such materials were capable of giving was implemented by making full use of modern technical knowledge of methods of surface preparation.

With regard to Mr. McIlmoyle's reference to the old practice of painting surfaces over and over again, in one case it had been possible to trace the painting history of a bridge back to 1860, and it had been found that altogether forty-two separate coatings had been applied, some of which were of tar sandwiched between white lead.

In discussing flame-cleaning as applied to maintenance work, the important fact that the flame-cleaning process completely dehydrated all the products of corrosion had been overlooked. That was an essential part of the process. If the corrosion products could be reduced to a dehydrated condition their removal was rendered much more easy, and therefore it was not necessary to have the same quantity of inhibiting pigments in the priming paint to guard against any corrosion which might develop afterwards. Despite all that had been said, the Authors considered that flame-cleaning was far more valuable than attempting to descale by the flame-torch method. It was not possible in all cases to remove scale by the torch and, having regard to the favourable factors involved in flame cleaning, the balance appeared to be definitely in favour of flame cleaning rather than descaling.

Mr. McIlmoyle's suggestion that structural steel should be phosphated before painting would entail no insuperable difficulty, but the problem was essentially one of manipulation and of cost. It could be taken, however, that if it were practicable to pickle a given part, it was also practicable to phosphate it. Comparison between paints applied on pickled and on phosphated surfaces, respectively, showed that phosphate coatings improved paint performance considerably.

Several speakers had stated that the steel industry could not comply with their requirements as to preparation of steel. It was time that the steel industry had the matter put fairly and squarely before them, in view of the maintenance problems which engineers had to face.

There was good reason for the fact that, in the film exhibited, the priming paints were shown to be applied by brush. In the majority of cases they were lead-based paints, and lead-based paints would not be sprayed for obvious reasons. The hope had been expressed that the time was not far off when priming paints would be produced from something other than lead-containing pigments. A number of leadless mixtures had been mentioned in the Paper (p. 29) and it could safely be predicted, in the light of present knowledge, that many good paints, possessing particularly good inhibiting properties, were quite outside the ordinary range of lead pigments.

Mr. Masterman's question of the painting of steelwork in "temporary" houses had been raised by innumerable people during the past twelve months. Having regard to the expectation of life mentioned, the light sections described would perhaps be better dealt with, not by phosphating them initially and painting afterwards, but by an aluminium or zinc spray with a liberal application of bitumen thereafter. If that process

were adopted there would be a very good chance of achieving the expectation of life to which reference had been made.¹

Disagreement as to whether mill scale should be removed or not had always existed. Most people were agreed that surface preparation was something which would have to be faced in future. If the Authors had done anything to bring about its fulfilment their object would have been more than achieved.

In reply to Mr. Fuller, brush-application was deliberately chosen for the priming coats used in the bridge tests described on p. 29, so as to keep the procedure in conformity with the existing practice in the Chief Civil Engineer's Department of the L.M.S. Railway. If spray-application had been necessary with the experimental paints, it could have been employed in the case of many of them without difficulty.

Mr. Easton had inquired whether exposure to the weather between descaling and painting would affect the beneficial effects of removing the millscale from the steel. The answer was that it was certain that in the case where steel structures were exposed to atmospheric corrosion the development of rust even after a comparatively short interval was detrimental to good paint performance, in comparison with behaviour on a freshly-descaled, unruined surface. The degree of deterioration so produced would naturally vary with the circumstances, but it was probable that under normal conditions of exposure in Great Britain the beneficial effects of descaling would be completely nullified in a shorter period than two years, unless the preliminary cleaning of the surface was so thorough as to be prohibitive in cost. Under certain conditions abroad, such as those obtaining at Khartoum, the effect of exposure to the weather would be less damaging, but in all cases the fundamentally sound procedure would be to apply the priming coat of paint immediately after the descaling operation.

Where welding was subsequently carried out, priming paints should be chosen with considerable discrimination. The important point to remember in painting over welded surfaces was that all residual welding flux should be removed from the surface before any further application of paint.

The Authors agreed with Mr. Shaw that tar or bituminous coatings should be applied as thickly as possible.

Mr. Bailey's comments on the performance of steel railway-wagons were of considerable interest, since they were based on years of practical experience and designing. One of Mr. Bailey's main contributions in that field, which was of considerable value in eliminating corrosion, was connected with the simplification and cleanness of design.

The Authors agreed with Mr. Ballard that metallic and paint coatings were complementary one to the other, and they had no doubt that the protective schemes of the future would make judicious use of combinations

¹ Mr. Masterman, in fact, referred to permanent houses and to a life of 60 years.

of both, since ample evidence existed to support the value of such combined schemes.

With reference to Mr. Bond's statement that it was unlikely that a structure in a highly corroded state could ever be brought into satisfactory condition for painting at an economic cost, it should be pointed out that that was already being achieved by means of flame-cleaning.

The Authors were in general agreement with Dr. Evans on most of the points raised by him, but, with regard to the comparison of the behaviour of red lead and iron oxide primers applied on an ideal surface, it should be observed that red lead primers invariably developed brittleness on prolonged ageing, owing to excessive reactivity between the pigment and the medium, and that that in turn resulted in loss of adhesion.

They were glad that Mr. Forbes had drawn attention to the preparation of steel surfaces by wet sandblasting ; but almost the whole of the experience accumulated from that process related to its operation in the United States. It would appear from the information available that it was very costly in application.

The Authors agreed with Dr. Main that, whilst corrosion was accelerated by the acids that were extracted from wood, the major cause of the corrosion of steel in permanent contact with wood was the retention of moisture.

There was much to support some of the views advanced by Mr. Preston, and the Authors hoped to explore them further in the course of a systematic series of tests on bituminous and similar protective coatings that were being planned by Joint Technical Panel J/PI (Paints for Structural Steelwork) of the Protective Coatings Sub-Committee.

In reply to Dr. Vernon's question regarding Table VII, the brushing of the panels that had been exposed for 7 days had been deliberately omitted in order to bring out clearly the detrimental effects of such exposure to the weather after descaling.

The Authors were unaware of any publication on the subject mentioned by Mr. Zimmerman ; possibly the nearest parallel was the protection of steel by ferrous "cladding" processes, in which the ferrous material was faced, either on one or on both sides, with a thin sheet of less corrodible non-ferrous material.

Some controversy still existed as to the mechanism whereby the presence of copper in steel led to increased resistance to atmospheric attack. According to some German investigators, a process of selective redeposition of copper on the surface occurred. If that view were correct, it was clear that a mechanical enrichment in copper of the steel surface should also lead to increased corrosion resistance. Beyond that it was impossible to generalize and it should be noted that in a case where a ferrous material was exposed to corrosion by immersion in an electrolyte the presence of embedded copper particles in its surface might lead to a deterioration in performance owing to the electrolytic effect of the copper particles, which would be cathodic to the steel base.