use to trace the causes of failure in steels, and to account for observations which are not explainable until the internal structure of the metal is seen.

The study of this science is still in its infancy, and much remains to be discovered before it can be said that the microscope will elucidate any problem. Nevertheless, the discoveries which have already been made are capable of very direct application in the work of testing steel, and when utilised together with the remainder of a metallurgist's stock in trade, the microscope now serves as a most valuable adjunct.

In conclusion, I wish to acknowledge the assistance of Messrs. P. Pecover and E. Curry in the preparation of the lantern slides.

DISCUSSION

Mr. Harricks: I am sure that I am voicing the opinion of this meeting when I say that we are very much indebted to Mr. Smart for the paper that he has read to us to-night. The examination of metals and alloys by the aid of the microscope has assumed so much importance during the last few years that every engineer whose business it is to design or to run machinery must feel that, to some extent at least, he should devote attention to this scientific aspect of the question. Of course, we must at the same time realise that research work must be left very largely to the specially trained physical chemist or the metallurgical engineer; but microscopical examination and its interpretation is within the capacity of every intelligent engineer. The quality and behaviour of metals can be so minutely followed by examination of their structure, that we must all be very keenly interested in what Mr. Smart has told us to-night.

In these days, when such liberal abuse is being laid at the door of the British for their lack of scientific research, it is satisfactory to notice that, referring to the subject before us to-night, British scientists apparently have not failed to realise the importance of this matter, and it is worth remembering that even Australia has provided one of the most prominent investigators in the microscopy of metals.

I can add very little of value to the discussion, but I was certainly interested to notice the author's remark that, although evidently the "fatigue" of metals is an acknowledged fact, yet it is an exploded theory that this is due to any change in their molecular structure. I fully appreciate the fact that Mr. Smart could not cover too much ground in the time at his disposal to-night; but I would like him, in reply, to give us an approximate idea of what he considers is the more generally accepted theory as to the causes of "fatigue." It seems to have been proved that material tested after having been subjected to repeated vibration, impacts, or shocks—even though none of these have approached the elastic limit of the material—has shown a decided reduction in tensile strength as compared with its original strength, and I presume that no distortion prior to fracture was observable. This seems to my mind, although I am quite unable to speak with any certainty, that the idea held by some people is right, viz., that, because no material is perfectly elastic, every time it is stressed some slight microscopic alteration in the structure takes place, and that it is only a matter of repeating the stress often enough to bring about fracture, possibly through the sliding planes.

The discrediting of the theory that metals crystallise due to repeated stresses has been, of course, a great surprise to very many engineers; but, in the face of what Mr. Smart has told us, there seems no doubt that what is commonly called crystallisation does not take place. It is, therefore, fairly evident that it is a very risky business to judge by the naked eye of the quality of a material merely by the appearance of the fracture. I suppose though, that upon broad lines, experienced engineers, chemists and metallurgists, can tell a very great deal by such an examination. It is, of course, quite noticeable the difference in the appearance of a fractured metal when the contraction prior to fracture has been great, for, especially in steel, the crystalline appearance seems to be so much finer.

I would like Mr. Smart on some future occasion to give this Association the benefit of a lecture or paper dealing specially with the fundamental principles of the formation of crystals in metals. I would also like him in reply to tell us whether, when steel is hardened by quenching, the structure is practically the same as when hardened by cold working. For instance, does a steel of the same hardness, and approximately the same carbon contents, assume the same form upon microscopic examination, whether hardened by quenching or by cold working?

In conclusion, I cannot withhold a word of admiration for the old metal-workers of half a century ago, when so little was known of the structure of metals. What they lacked in scientific knowledge seems to have been compensated by excellent judgment.

I have much pleasure in putting the vote of thanks to the meeting, and asking you to carry it with acclamation.

Mr. W. Poole: It affords me very great pleasure to propose a vote of thanks to Mr. Smart for the very able and clear exposition of his subject which he has given us to-night.

He has given in a very interesting manner the results of long research in the study of steel.

Although engineers may not find it necessary to make a deep study of this subject—for, as Mr. Smart says, it is purely a metallurgical matter—they should at least be cognisant of the results of such study. Most engineering schools now include in their curricula a short course of study of commercial metals and their alloys, their chemical and physical properties, and the effect of small quantities of other constituents whose presence may be intended or accidental. A knowledge of the main results of such work, especially of iron, and to a less extent of copper, lead, zinc and antimony, is essential in every branch of engineering, and every engineer should therefore be conversant with the principal results of research in this subject.

Mr. Smart has referred in his lecture to the way in which alloys in a molten state separate and segregate. This is a matter of very great importance to all metallurgists. It was long ago known that the sampling of smelter bullion, e.g., copper or lead containing gold and silver, might give results which differed very materially from the true average. Careful investigation showed that during cooling, the constituent alloys segregated in a very marked but consistent manner. Bullion bars are now, therefore, sampled in different positions on the same or similar bars, the separate samples being mixed to give the final average sample.

The segregation of alloys is also shown in a remarkable manner in refining lead bullion. A small amount, even down to a minute quantity of antimony, shows as a frosted spot on the surface of a bar of lead that has been allowed to cool. This enables the furnace man to at once determine with as much certainty the point at which the operation may be discontinued, as can be obtained by a lengthy and delicate chemical analysis.

The separation of minerals and their order of crystallisation is very clearly seen in the examination of thin sections under the microscope, using plane and polarised light and other means at the disposal of the petrologist.

Mr. Smart has brought before us very clearly the great changes that take place in the body of steel under heat treatment. We all know, as engineers, that the physical properties of steel are very greatly affected by tempering and annealing, and Mr. Smart has shown that this is due to definite alterations in the component parts of the steel.

He had great pleasure in proposing a hearty vote of thanks to Mr. Smart for his very interesting and instructive paper.

Mr. McEwin: I have much pleasure in seconding the vote of thanks to Mr. Smart, and I would like to thank him very much for the trouble he has taken in the preparation of his lecture. There is evidence of his pains in the admirable set of slides he has obtained to illustrate his address, and we are much indebted to Mr. Smart for the trouble he has taken.

The lecture brings home to us all the value of the microscope in all branches of engineering; I have found it very useful in searching oils for the presence of emulsified water, which could not be easily detected otherwise. It may also be used in connection with welding, for the examination of specimen welds, and in particular for the investigation of the changes which take place in the metal adjacent to the weld. In many departments of engineering it will also be found very valuable. The vast field covered by Mr. Smart's able lecture will come home to us more as we meditate upon it.

One of the most beautiful and interesting of processes in connection with the study of steel is the heat testing of specimens, a method which gives very satisfactory results.

This process presents the only means by which carbides and phosphides of iron can be distinguished from one another when both are present at the one time in a specimen of iron or steel. I believe that the usual result is that the carbides show a red color, and the phosphides a blue color.

We all learned something about crystallisation and its effect on metals. Very few engineers would believe, unless assured by a man who has such a knowledge of steel as Mr. Smart possesses, that steel is in a crystallised form when it leaves the rolling mill. The lecturer had not brought forward any decisive proof of the crystalline constitution of the grains of the metal. The slide which illustrated the effect of strain upon steel was some evidence that crystals were present in the grain, as also were the references to twinning and slip bands. It would be interesting to know whether fracture takes place along solid points, or whether it takes place indiscriminately.

Reference was made to the controversy respecting the existence of the "recalescence point" which marks the distinction between "alpha" and "beta" steel. The fact that the magnetism of steel disappears at the temperature corresponding to this "recalescence point" is proof that an important change of character takes place here.

There is little doubt that the microscopy of steel has led to improvements in the manufacture of steel in spite of the great discoveries which had already been made in this branch of production. An instance of the practical value of scientific methods is that of the rejected bayonet examined by the lecturer.

The lecture was a testimony to the value of applied science—the engineer must look to his technical education to hold his own in the scientific world. The manner in which the chemist is coming to the fore has taught us a lesson. The engineer should pay more attention both to physical and chemical science, and should lose no opportunity of establishing his position on the technical side of his profession.

Mr. FRASER: We have seen from the interesting paper and slides put before us to-night of what assistance the microscope can be to engineers when in capable hands. It is an easy matter to look through the instrument, but labour and skill are required to prepare the specimens for examination, and then one must have the necessary knowledge to understand what is revealed by the microscope, and this can only be acquired by a close study of the subject.

With regard to crystallisation, supposed to occur through repeated stress, Mr. Smart has pointed out that steel has a granular formation, each grain having a crystalline structure, and that the fracture occurs along the planes of cleavage of the crystals, giving the fracture a crystalline appearance. I have noticed when breakages have occurred in a piece of machinery, for instance, a crane chain, that the fractured section has a bright crystallised appearance, but that there is generally a dark spot or centre. I should like to ask Mr. Smart how he would account for this.

Mr. OAKDEN: I have had great pleasure in being present to-night. It has been extremely interesting to me to hear this lecture from Mr. Smart. It has been only too short. As an engineer, I should like to hear Mr. Smart give more details of the separate sections. A story could be told of almost every section he has put on the screen.

I wish to thank the Association for the invitation extended to me as a stranger.

Mr. SMART, replying, said that he had only been able to deal with the subject of "fatigue" very briefly. This branch of the subject might well occupy the whole of an evening. It was gratifying to note that some of the most important work on "fatigue" had been carried out by an

Australian—Dr. Rosenhain—who was now head of the Metallurgical Department of the National Physical Laboratory. According to Rosenhain, the grains of metal—which are themselves built of crystals—are separated from one another by thin boundaries containing a film of supercooled liquid metal forming an amorphous cement. When subjected to static stress, the metal yields by a sliding of the crystals within the grains along their gliding planes, but the boundaries themselves simply change in shape. Fracture ultimately takes place across the cleavage planes, never around the boundaries.

If, on the other hand, the metal is subjected to repeated alternating stresses, there is a certain limiting stress which causes one or other of the grains of which the metal is composed to undergo slight slip. Rosenhain has shown that eventually the minute slipping causes tiny fissures to extend inwards from the boundary, and which develop into a crack extending right across the grain. The failure of one grain causes the load on the grains surrounding it to be increased, and the process passes on from grain to grain until the whole mass of metal breaks down. "Fatigue" fractures thus show practically no deformation of the grain structure, and the surfaces revealed have a crystalline appearance, since the crack has passed through the gliding planes of the crystals which build up the grains.

The true elastic limit of a metal is the limiting stress below which such slipping does not take place, and this limit is the "safe range" when the metal is to be subjected to alternating stress.

In all normal cases of fracture the boundaries of the grains remain intact, but Rosenhain has shown that as the temperature rises the adhesion of the boundaries diminishes, until, at temperatures over 900 deg. C., a fractured bar of iron shows signs of disruption around the boundaries themselves. At such temperatures the resistance of the

metal is dependent on the rate at which the strain is
metal is dependant on the rate at which the strain is applied, a property which is characteristic of viscous or quasi-liquid substances. As the melting point is approached the most ductile metals exhibit a very high degree of inter-crystalline brittleness, this having been shown very clearly by Ewen in the case of gold, bismuth, and other metals.