The inspectors, as their reports show, take a keen interest in training and education, and report on the training centres, training faces and courses of instruction in each division. In 1956 more than 17,000 juveniles and more than 15,000 adults received preliminary training ; these figures indicate the immense task of training in the coal industry, especially as face training has to be arranged and courses for potential shot-firers and potential deputies (quite apart from courses for senior officials, which are not referred to in detail).

Sections on health and welfare refer mainly to work carried out in improving dust control, ventilation, lighting, sanitation and so forth, and to the provision of medical centres at collieries.

Each divisional report includes a section devoted to horses. Although the number of horses employed at collieries is decreasing, more than 10,000 were employed in 1956. In general, the miner is devoted to his horses and they are well cared for.

Although the general pattern of the reports is similar, they are not stereotyped. Probably few people unconnected with the mining industry will read them, but they are very well worth reading, for they are personal reports and are far from the dry-as-dust documents they might have been.

The reports for 1957 of H.M. Inspectors of Mines and Quarries under the Mines and Quarries Act, 1954, have also recently been published ; these are the first reports under the 1954 Act which became effective on January 1, 1957. It makes provision for all classes of mines and quarries to be dealt with together, and the Inspectors' reports include, in separate parts or sections, reports on coal mines ; mines of stratified ironstone, shale and fireclay ; miscellaneous mines (including metalliferous mines) ; and quarries*.

The general pattern is similar to the earlier divisional reports, which dealt only with coal mines and other so-called stratified mines. As may well have been expected, by far the greater part of each report deals with coal mines and the conclusions are similar to those for 1956.

Until 1957 the reports of H.M. Inspectors of Mines and Quarries on metalliferous mines and quarries were presented in a single publication for the whole country by H.M. Chief Inspector of Mines and Quarries under the Metalliferous Mines Regulation Act, 1872, and the Quarries Act, 1894 ; the last report under these Acts was published early in 1958 and referred to the years 1954–56. The new arrangement under the 1954 Act whereby H.M. Inspectors report annually on all mines and quarries in their division is more convenient in many ways than the former biennial reports.

The new reports show that particular attention is being paid at quarries to dust prevention and dust suppression and to encouragement in the use of protective clothing, especially safety hats, which many quarrymen seem loath to wear. S. G. WARD

* Reports of H.M. Inspectors of Mines and Quarries under the Mines and Quarries Act, 1954, for 1957. Northumberland and Cumberland Division. By H. Hyde. Pp. iv+41+6 plates. 3*s*. 6*d*. net. Scottish Division. By W. Widdas. Pp. iv+41+6 plates. 4*s*. net. North Western Division. By G. Hoyle. Pp. ii+42+6 plates. 3*s*. 6*d*. net. Durham Division. By W. Brown. Pp. iv+23. 2*s*. 6*d*. net. South Western Division. By T. A. Jones. Pp. iv+28+4 plates. 2*s*. 6*d*. net. West Midland and Southern Division. By J. E. Henshaw. Pp. iv+34+2 plates. 3*s*. net. North Eastern Division. By C. W. Scott. Pp. ii+44+7 plates. 3*s*. 6*d*. net. East Midland Division. By W. B. Brown. Pp. ii+38+7 plates. 3*s*. 6*d*. net. (London : H.M. Stationery Office, 1958.)

PRESSURE WELDING OF METALS

WELDING engineering is a profession now well established in industry and is supported by a research association and a technical institute. In Britain (unlike the United States and the U.S.S.R.) it has not achieved independent status at any university, and it is therefore practised by metallurgists and mechanical, electrical and civil engineers, in whose training it has occupied a very subsidiary role. However, as a result of the division of metallurgy into physical and industrial aspects at the University of Birmingham, research into and the teaching of the basis of metallic jointing practice now figures prominently in the Department of Industrial Metallurgy. To supplement the academic work, occasional conferences are organized to promote the exchange of information and ideas with other workers in the field. The second of these conferences, on the pressure welding of metals, was held on June 19, under the chairmanship of Prof. E. C. Rollason, head of the Department of Industrial Metallurgy, and was attended by ninety representatives of industry, the research associations and the universities.

After explaining the purpose of these conferences, Prof. Rollason reviewed the origins and development of the practice of pressure welding and the progress that had been made towards establishing a theoretical model. Three papers were then presented, the first by Mr. J. A. Donelan (Research Laboratories, General Electric Co.) dealt with industrial practice, the second by Messrs. L. R. Vaidyanath, M. G. Nicholas and D. R. Milner gave an account of the researches being carried out at the University of Birmingham, and the third paper by Dr. E. Holmes (University of Nottingham) was concerned with the relative importance of movement at the interface, oxide break-up, and the deformation of surface asperities upon bond formation.

The idea of joining metals by pressure is not new, as it has been employed in the hammer-forged blacksmith's weld from the earliest days of the use of iron ; this, however, is a special case in that it depends on the squeezing out of a molten layer of slag between the two components to be joined. The general practice of pressure welding metals, without melting, was established in 1887 with resistance heating used to aid the deformation of the interface ; then, during the Second World War, the cold welding process was developed in which metals are joined at room temperature. The majority of metals can now be pressure welded, if not at room temperature, then at higher temperatures. The advantages of the process are that the joint possesses none of the weaknesses inherent in the cast structure associated with the more normal welding techniques, and it is the only metallic jointing process that can be carried out at room temperature, and is therefore particularly suitable to the canning of delicate components such as detonators or transistors. One of the widest applications of pressure welding is to the production of ply metals by rolling, so that the advantages of the properties of two or more metals or alloys can be combined, for example, to provide corrosion resistance, as in the cladding of high-strength aluminium alloys with a thin layer of super-purity aluminium, or for economical reasons as in the cladding of mild steel with a thin layer of stainless steel.

Pressure welding practices developed empirically, and it was soon found that metals varied markedly in their welding characteristics, the criterion of weldability usually adopted being the amount by which two pieces of metal when placed together have to be deformed in order for them to join : thus, for example, at room temperature overlapped strips of tin and lead require a reduction in thickness of about 20 per cent, aluminium and copper 50 per cent, and nickel and iron 80 per cent. Cold welding is largely applied to aluminium and copper, and Mr. Donelan cited many applications in the electrical industry such as joining the ends of wires and rod, the formation of cable sheath from strip, and the fabrication of electric kettles and refrigerator coolant panels. Mr. Donelan stressed that for successful welding the most important factors are the surface preparation of the material (a degreasing treatment followed by scratch brushing being preferred), and the shape of the deforming tool.

The understanding of the phenomenon of pressure welding lags behind its practice and no satisfactory theory has been developed, although several hypotheses have been advanced as to the nature of the controlling parameter. When pressure welds could only be made at high temperatures it was considered that diffusion at the interface was essential to bring the surfaces into atomic contact, and for this reason that welding was enhanced at the recrystallization and transition temperatures, at which the rate of diffusion was considerably increased. With the advent of cold pressure welding emphasis was transferred from the influence of the temperature of welding to the pressure applied, which then came to be regarded by some workers as the controlling factor. These hypotheses, however, take little account of the practical necessity for careful surface preparation before welding, and more recent theories have concentrated on this aspect, in one case the penetration and fragmentation of the oxide film being regarded as critical, whereas in another case the difficulty of bringing roughened surfaces into intimate contact has been stressed. An alternative hypothesis has been advanced which implicitly assumes that the formation of bonds presents no difficulty, but that on release of the applied load these bonds are at least partially broken apart by elastic recovery forces which vary from one metal to another. Finally, there is the possibility of relative movement between the joining surfaces which, as workers in the field of friction have shown, leads to the formation of welds that are responsible for frictional restraint. None of the models suggested has been developed in detail and none of them can explain all the observed facts.

The difficulties in making an analysis of bond formation are : first, the large number of parameters involved ; and second, the fact that no satisfactory method has been developed for the measurement of the degree of bonding or weld strength which is obtained. Part of the theme of the work of Vaidyanath, Nicholas and Milner was that the mechanism of pressure welding is best investigated via the roll bonding process, since for practical purposes the reduction is uniform throughout the composite and it is possible to measure the bond strength by a test giving results which are more amenable to analysis than those available hitherto. This work has led to the development of a theoretical model for the maximum joint strength that can be obtained from the concept that oxide films are completely brittle, so that when the interface is extended, areas of virgin metal are exposed and these are the sources of potential bonding. However, the problem remains of why these virgin metal areas do not always join. From evidence on the effect of pressure, time, temperature, and exposure of the surface to the atmosphere prior to rolling, the authors concluded that a correct theory must involve considerations of atomic movements during deformation, diffusion and the solution of entrapped gases.

When dissimilar metals are welded, further problems arise in that if the two metals possess different mechanical properties they will not deform in the same manner and, in addition, alloy layers will develop at the interface and have a marked effect on the joint strength. Dr. Holmes showed that when dissimilar metals are bonded by rolling there will also be relative movement between the two surfaces as they enter the roll gap and that this could lead to substantial bonding without much deformation, the bond strength increasing with the amount of relative movement and with the applied load under which the movement was carried out. From further experiments, designed to examine the relative importance of the difficulty of bringing rough surfaces into intimate contact and that of penetrating the oxide film, Dr. Holmes reached the conclusion that for conditions under which the flow of metal was restrained oxide break-up was difficult to obtain, whereas, since restraint of necessity involves higher pressures, the deformation of asperities was readily achieved. Conversely, for conditions of low restraint, metal flow and oxide break-up took place readily and the deformation of the surface asperities became the controlling process.

The points raised during the discussion showed that pressure welding is contributing to the solution of some of the problems arising from modern technical developments, two examples of the use of cold welding being the joining of the trans-Atlantic cable and the fabrication of complex patterns of frozen mercury for precision casting. The disadvantage remains that in many cases considerable deformation is required, but a recent development has shown that this can be very much reduced by the application of ultrasonic vibration during the welding process. The use of impact loading was also discussed, but the results were inconclusive ; some indicated little difference, while others suggested considerable improvements, from the bond strengths obtained by deformation at conventional speeds. The divergence of the opinions expressed on the theory of pressure welding showed how little can be regarded as universally acceptable, and the ultimate answer will probably show that the controlling parameter varies with the conditions of welding. The technique of surface preparation prior to welding received considerable discussion, and it is found that the best welds are achieved with scratch-brushed surfaces : with many other surface treatments, or no surface preparation, it is often impossible to obtain any bonding. That no satisfactory explanation could be offered for the success of the scratch-brushing practice demonstrated again the inadequacy of the present state of the theoretical treatments of the subject.

D. R. Milner