Achievements through Welding*

By Dr. R. WECK†

ABSTRACT—Welding is a vital part of production technology distinguished from other production techniques by two features : it is far more widely used than almost any other production technology but is also much more difficult, troublesome and problematical than machining, forging, casting or extruding. The successful solution of welding problems as they occur, and which continues to stimulate new material and process development, has played a crucial part in modern technological and industrial achievement over an extremely wide field from electronics to shipbuilding power generation but—and this is possibly even more important, for the future—the solution of these problems have forced a gradual but irresistible revolution in fundamental concepts and ideas in the field of material development in design and in production.

I was greatly honoured by your invitation to deliver this opening address on the occasion of your 21st Anniversary meeting and am delighted to be here and able to convey to you my own Institute's warmest congratulations on your 21st birthday and our very best wishes for future prosperity and growth both in numbers and influence. It is a happy coincidence that my own Institute is celebrating its Jubilee this year and though we are a little older, we would not claim to be wiser. We would, however, also not concede that our own vigour can no longer match yours even if, from time to time, the old country—as I believe it used to be called here—gives this quite erroneous impression.

You have chosen as the theme for this meeting "Achievements through Welding", thus proclaiming your own belief—which of course we share—that welding has made a tremendous, even if widely unrecognised, contribution to the progress and the prosperity of all mankind. It is saddening that advances in science and technology no longer inspire the same sense of adventure, the same kind of admiration and enthusiasm they created in my own generation and that, amongst your people today, technological and industrial progress have become almost dirty words. Only their harmful and very largely avoidable effects on the environment are singled out and the vast benefits for this planet's population—growing at an alarming fast rate—are ignored. The cargo of the super-tanker that may pollute the beaches also, it should be remembered, brings life to millions of poor farmers when its cargo is converted into fertiliser. The power station producing atomic waste also provides warmth, comfort and entertainment for the old and sick.

To this particular audience, I am sure, I need not extol the benefits of technology but perhaps it is time for technologists to speak up—not to defend themselves—but to demonstrate that but for their endeavours, life on this planet would long ago have become impossible for hundreds of millions that would surely have perished from starvation or disease soon after birth. Technology has allowed us to multiply and to lead longer, fuller, richer and better lives than our forebears lived a hundred years ago.

The young must learn that accidents have always happened, that life has always been perilous and that there can be no achievement without risk. Indeed, it is only by the use of better technology in industry that we can hope to reduce the risks and eliminate threats to our environment stemming not from technology but from the population explosion. Natural disasters like floods, earthquakes and famines have always occurred but technology has placed us into an immeasurably more favourable position and given us the means to bring immediate help to those struck down by disaster, to stop epidemics and to restore normal conditions of life to stricken communities quickly.

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† Director-General of the Welding Institute, U.K.

It was in 1873, a hundred years ago, when Jules Verne published his famous novel. Had anybody in those days actually succeeded in travelling around the world in eighty days, it would undoubtedly have been acclaimed as a great achievement. Nobody, I am sure, will acclaim me for doing the same thing in less than half the time with a good deal of work en route because what was virtually impossible a hundred years ago has become commonplace today. Achievement is indeed relative and the odds must be heavily weighted against its accomplishment. Has anything been achieved through welding in this sense ? There is no other branch of production technology that had to contend with such heavy odds against success. Welding of a kind has of course been practised for centuries. As a production process in its present forms, however, its acceptance was slow in industry. For a long time welding was suspect and thought unreliable, even dangerous as a joining process, with every justification. Its future certainly did not look too promising when a few pioneers here and there started to use welding, surprisingly often with complete success. Problems and failures of course soon appeared and had it been possible to foresee all the problems that gradually surfaced—in an objective scientific assessment at the beginning—welding would certainly have been considered a poor candidate as a universal joining process. But this is indeed what it has become.

I need not spend much time discussing the problems. I am sure all of you are only too familiar with them from your own experience. A process that requires liquefaction and resolidification and that destroys the properties of materials achieved by careful alloying working and heat treatment, that requires not only the imposition of narrow limits on chemical composition for the materials to which it is applied, that calls for special ski'l and precautions to avoid dangerous defects, that promotes shrinkage and distortion and leaves the structure full of residual stresses, whose effect on safety was not—and to some extent is still not —completely understood, is certainly afflicted with more serious disabilities than even the traveller round the world in eighty days might have had to contend with in 1873. When it comes to having problems, welding is unique in comparison with other production technologies such as forging, casting, riveting and metal cutting. It is also perhaps unique, paradoxically, that it has become indispensable to a larger number of different industries than any other branch of production technology and that even industries not directly concerned with metals at all such as the oil and chemical industries, are utterly dependent on welding for the fabrication of the plant they use. Even the electronics industry has had to turn to welding for its microscopic hardware.

To have successfully overcome such grave disadvantages is indeed, I believe, a great achievement and a testimonial not only to men's ability to defeat adversity by ingenuity and perseverance but for the cost effectiveness of research which it has become increasingly fashionable in recent years to disparage.

There have of course, been setbacks and minor disasters from which no country including yours has been immune, simply because mankind seems to prefer learning the hard way by experience rather than research and engineers are no exception. Yet, these setbacks are insignificant in relation to the prizes we have now. The rewards of ingenuity and perseverance have been impressive. In shipping alone, the savings from the increase in carrying capacity as a result of weight reduction by welding together, with the reduced fuel consumption resulting from the smoother hull must by now run into many billions of dollars. The production of cheap fertiliser so vital for the overpopulated world depends on large capacity plant which, without welding, could never have been made. Nor could power be generated at anywhere near its present low cost because, without welding, the heavy pressure vessels and superheaters for high pressure and temperatures operation that has now become common could never have been made. Without welding, the resources of oil and natural gas could neither have been tapped nor transported, stored and processed. Much concern is voiced at present about a possible world energy crisis in the near future. It is quite certain that without welding we would already now be right in the middle of it. Could we have moved the quantities of fuel now needed by the world without the supertanker, could you have successfully built the penstocks and turbines for your own Snowy Mountains scheme without welding ? Perhaps, but without welding we could certainly not even have attempted the construction of atomic power stations to supplement our resources of fossil fuels and water power. To have attempted the construction of containers for highly radioactive materials without the use of welding which alone provides leak-tight joints would have been asking for trouble. How, for instance, could one produce 300ft. lengths of thin walled finned tube of three different materials, tightly coiled round a central core and connected to a tube plate inside a thin stainless steel casing, if not by welding. This, basically, is the once through boiler for the advanced gas cooled reactor now under construction in Britain.

Whatever system will be adopted for future atomic power stations and whatever new sources of energy will be tapped, welding will undoubtedly continue to be required as a method of joining and probably in increasingly sophisticated forms. The choice of system itself may well hinge on finding satisfactory solutions to fabrication problems and their effect on construction costs. For the pressurised water reactor, a pressure vessel 350 mm thick may be needed using steels covered by our present fabrication experience. There are few fabricating shops in the world capable of producing vessels that size and public utilities who will be ultimately responsible for the safety of these vessels during a long operating life are not entirely free from concern at the prospect.

It is of course not only power generation where progress was made because of advances in welding. Wherever we look in our industrial civilisation whether it is water supply, transport, food processing, storage and preservation, we rely on welding. Production of natural fibres cannot satisfy the increasing world demand by a growing population with increasing purchasing power so that even for our clothing we depend on welding to make the chemical plant for the manufacture of artificial fibres.

New Freedom

The exploitation for technological and industrial progress of what was not so long ago a new technique has to start at the drawing board and one of its great attractions, at least in the beginning, was the apparent simplification of design and the new freedom it suddenly gave to the designer's imagination. In contrast with concrete, which did not obey Hooke's Law, and where design could not be based on the mathematical theory of elasticity without experiment, steel design had become completely stereotyped and frozen by a set of rules based on simplified concepts of the theory of elasticity. It took a very long time for steel construction to escape from these shackles but welding proved to be the key that opened them. The apparent simplicity of course was deceptive and only superficial. Welding, as it turned out, makes much greater demands not only on the designer's ingenuity but on his real understanding of the material and its properties, the many technicalities of the joining process, a much deeper understanding of structural behaviour and mechanics and much more judicious and profound assessment of details. Also, for the first time, the designer had to concern himself with the problem of real structural safety rather than the fictitious concepts of safety factors and permissible stresses.

I hope you will not consider it indelicate if, in this context, I mention box girder bridges. It is inevitable that accidents such as the one you have experienced in this country should produce a highly charged emotional atmosphere in which objective judgements become difficult, and quite unjustified prejudices may be generated against particular forms of construction. This situation is not new in welding. Welding itself as a form of joining, and for a very long time, was itself suspect because of failures resulting from inadequate understanding of the process and the consequences of its application. The first brittle fractures in bridges soon followed by numerous brittle fractures in ships again produced a strong reaction and a wave of suspicion directed against large welded steel structures that could not be stress-relieved. Now box girder bridges are under a cloud.

Yet, just as research solved the brittle fracture—and many other welding problems—the box girder problem will be solved. The tragedy is that we always have to wait for accidents before even the very modest sums required to solve problems before accidents occur are made available. It is curious that in relation to what is called "high technology", such as aerospace, the public has been brainwashed into accepting not only the goals but the astronomical research and development expenditure needed to achieve them, whether we need them or not. The invention of the term "high technology" was indeed a masterpiece of advertising genius. Nobody can define how "high technology" differs from low technology except that it costs more. The instability problem of thin walled welded structures like many other problems in the metal fabrication field, had been identified more than twenty-five years ago but very little, if anything, could be done about it. Engineers working in fields other than high technology have become conditioned to attempt advances extrapolating from scant experimental data by the use of unproven theory.

It is really not surprising that from time to time an accident reminds us that progress needs research in every field and not only in those dubbed "high technology".

Box girders may be under a cloud at the present time, but this should not blind us to the real advance they represent in comparison with other forms of construction. The user of course may not care whether he drives over a bridge made from concrete or steel and you have world famous examples of both in this country. Only steel, however, will provide long, unsupported spans where these are needed and the box girder made possible by welding is economically and aesthetically a superior solution compared with more traditional forms. The Severn Bridge in Britain, I am sure, will be looked upon by future generations of engineers as a landmark —in both senses of the word—in the development of suspension bridge design.

Change of Thinking

The greatest, and to my mind, in its long term effects, most decisive and important achievement, cannot be shown in pictures and is not very obvious. It is the change welding has forced on our thinking. Our confidence in our accepted and time-honoured methods of judging the quality of materials and the risk of structural failure has been shaken to its foundations. Consider the logic of what we do. We use the most sophisticated methods of analysis and the most advanced computers to determine stresses with great accuracy and then limit these to some arbitrary fraction—defining a safety factor—of a material property such as yield point laid down in a standard specification. How meaningful and realistic is this. On the one hand, we find that, even before loads are applied producing these calculated stresses, there are already stresses present as a result of welding much greater than those we have decided are the limit to be permitted and that these stresses have in general no effect on the safety of the structure. On the other hand, we have experienced failures in tests or in service despite the fact that the stresses considered safe had not even been attained. We have closed our eyes to this and other inherent contradictions between theory and experience, yet the time has surely come when we must face this problem and admit there is something wrong somewhere.

We have indeed been aware for a very long time through the work of Sir John Baker and Professor Roderick that in particular types of structures, the welded steel frame with rigid joints, the stress criterion is totally irrelevant and safety must be assessed not in terms of stress but in relation to a definable state of collapse when the structure has become unserviceable. It is significant that this is essentially a geometric criterion, particularly if one uses the actual stress strain relationship rather than an idealised one. This move towards geometry and away from elasticity is increasingly apparent in other fields. Assessments of safety against fatigue failure though still expressed in terms of stress are essentially assessments of geometric parameters that can only at present be determined experimentally.

Even the brittle fracture problem is fundamentally a problem of geometry. We know that even very brittle steels do not suffer brittle fracture in the absence of a notch and it is interesting—and was almost predictable—that recent advances in the field of fracture mechanics have produced solutions permitting the assessment of the brittle fracture risk from an existing defect by deleting certain geometric parameters such as COD to geometric parameters of the defect without—and this is most significant—either involving conventional stress calculations or conventional mechanical properties.

These fundamental changes in our thinking which have shaken our time-honoured belief in the relationship between stress and failure have of course also forced us to look much more critically on the real significance of mechanical properties. Many engineers still find it difficult to accept that increasing section size or using "stronger" materials structures do not necessarily become safer and may indeed become less safe. Experience with high tensile steels, particularly when they were first used in welded construction, have amply demonstrated this fallacy. Indeed, even very high strength materials, such as maraging steels, when used at permissable stresses increased in proportion to "strength" are no safer—and may be less so than low strength steel if fatigue has to be considered. All this is not completely new. Though perhaps we were not conscious of the facts because we operate with a permissible stress concept, buckling problems always have been essentially geometrical problems. The slenderness ratio of columns—of which the permissible stress is a function—is a purely geometric parameter, and permissible buckling stress cannot be increased in proportion to increases in yield point, regardless of geometry. High tensile steels were always known to offer only limited advantages in compression members.

The liberation of the designer from the straight-jacket of conventional forms has been the principal element in achieving spectacular advances in plant construction during the lifetime of your Institute over a wide field of industry including the production of equipment for defence which for obvious reasons I have not previously mentioned. This departure from convention has increasingly confronted us with problems, basically stemming from inherent contradictions and inadequacies of established design procedures tied to very elementary concepts of material strength and quality. The whole field of what used to be called "strength of materials" is undergoing quite radical conceptional changes as we gain new insight into the true mechanisms of structural failure, which depart more and more from conventional elasticity concepts. The whole field of fracture mechanics has developed from investigations into the brittle fracture problem of welded structures but has had repercussions in much wider areas of design quite separate from welding.

If we look at human progress through the ages, we find its main spring in the evolution of new ideas from the conflict between established and generally accepted principles and the reality of experience. This has not only been the case in science and technology, but in the development of our social and political fabric, in medicine and in law. Change of course is usually rather discomforting and may produce a feeling of insecurity. It is therefore not surprising that what I have considered here as a great achievement others may see as a difficult, disturbing and most undesirable complication associated with welding.

I believe, however, that change is inevitable and that welding has opened the path to new achievements in metal construction compelling us to establish a more rational basis for the development of metal alloys and their more imaginative and sensible application.