Welding Research in the World

What is the status of welding research around the world ? What are the areas of principal effort in the research organisations, in industry, and within the Commissions of the IIW, and what are the likely future research directions ? *Richard Smith* reports on the presentations at an international congress which addressed these questions.

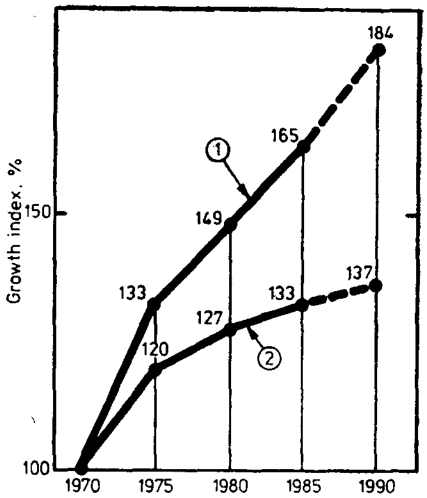
With the ambitious aim of reviewing present and future global trends in welding research, an international congress with the theme 'Welding research in the world and the challenge for the 80s' was held in Boston on 13-14 July 1984, preceding the Annual Assembly of the IIW. Sponsors of the event were Commission VII of the IIW 'Welding research strategy and collaboration', the Welding Research Council and the American Welding Society; supporting organisations were the American Society for Metals and the Welding Institute of Canada ; and general Co-Chairmen were Dr G W Oyler, Executive Director, Welding Research Council, USA, and Professor Y Arata, Director General, Welding Research Institute, Osaka University, Japan.

'We are participating in what may in future be seen as a historic event,' said Dr Irving Oehler in his welcoming remarks, and certainly it is unlikely that there has ever before been such a gathering of distinguished welding researchers. In some 38 presentations by experts from 18 countries there was such of interest, particularly in the resumes of the work of the IIW Commissions, in the descriptions of how research is organised, financed and staffed nationally and internationally, and in the prognostications on future trends. But it was disappointing that a full programme allowed no time for discussion, and at times the most distinguished lecturers can fall prey to the temptation to lecture on their favourity theme rather than follow their brief. It was also unfortunate that the returns on the 'world wide welding survey' originated by IIW Commission VII had not been analysed, so that only an exposition of the questions was possible, but not of the answers.

To set the congress in context, Jan Skriniar, President, IIW, and Director, The Welding Research Institute, Czechoslovakia, noted that many countries are considering the best methods of conducting welding research, as it continues to diversify. 'Welding has sometimes been called the pupil of steelmaking' he said, 'but nowadays sometimes the pupil teaches the teacher"!

KEYNOTE ADDRESS

The keynote address, 'State of the art and prospects of development of welding technology in the CMEA member countries', prepared by Dr B E Paton, Director, E O Paton Electric Welding Institute, was presented in Dr Paton's absence by one of his colleagues. Information was included from six CMEA (Council of Mutual Economic Assistance) countries—Bulgaria, Hungary, GDR, Rumania, the USSR and Czechoslovakia. A common trend in welding engineering development in these countries in the last 5-10 years is the intensification and improvement of quality. The annual increase in fabrication of welded metal structures is over 3 Mt and this rate of growth will be sustained during the next few years, although the growth in the number of welders will not be in proportion, see Fig. 1.



1. Fabrication of welded structures (1) and number of welders (2) in the CMEA member countries (growth index %)

—Reprinted from "Metal Construction"—November, 1984 with permission.

To overcome materials problems, the technology of manufacturing multi-layered pipes has been developed in the USSR, and the applications of multi-layer products and structures are expected to be considerably increased. A wide application of welded and glued structures in polymeric materials is also expected in the near future. Developments in the technology of welding of specific structural materials include copper welding without preheating, explosion welding of transition pieces in steel-aluminium-aluminium alloy; friction welding of dissimilar metals and alloys, and the technology of welding stainless and heat resistant steels of martensitic grades.

NDT receives serious attention, for example in Hungary mobile installations have been developed for the application of acoustic emission techniques to structures during fabrication and in service. In gas shielded welding, two and three component mixtures are widely applied and four component helium based mixtures are under investigation. Use of wires microalloyed with rare earth elements such as cerium has been found effective in minimising spatter during gas shielded arc welding.

Narrow gap submerged arc welding is being used in manufacture of thick wall weldments, mainly for power generating plants, and fluxes for low alloy and high alloy steels have been developed to broaden the applications of this technique. Electroslag welding technology is also being advanced. The method was used recently for welding the frames of a heavy rolling mill and it has also been used in manufacture of equipment for nuclear and hydroelectric power stations.

There has been considerable development in understanding fundamentals of flash butt welding, and this is one of the principal techniques used in constructing major gas and oil pipelines. Dr Paton also noted developments in automation and robotics, in electron beam and laser welding, in friction welding and in surfacing.

STATUS OF WELDING RESEARCH

The first session covered the status of welding research and the strategy for the late 80s in various geographical areas.

The European Community

Reporting on welding research in the European Community countries, Dr A A Wells, Director General of The Welding Institute, UK, explained that while the IIW does not recognise regional groupings of countries through affiliations, such groupings do exist for convenience. The European Council for Cooperation in Welding (ECCW) is one of these groups, whose activities in welding research Dr Wells described. There are eight welding institutes within the ECCW, all non-profit organisations, and all, with the exception of the Institute for Industrial Research and Standards (IIRS) in Ireland, wholly concerned with welding and closely related technologies. Except the IIRS all the Institutes are also concerned with learned society activities and, to varying degrees, with education and training as well as research and development.

In 1982 the total welding technology revenues for the Institutes, excluding the IIRS, were about 80M ECU (one ECU approximately equals US $0.85) and the total value of research programmes under review amounted to around 20M ECU.

Most welding processes are in use in Europe, but there is particular interest at present in mechanised and automated electric arc and resistance welding, solid phase processes such as friction welding, and in the newer high energy density processes typified by plasma, laser and electron beam welding. There is much attention also to welding of steels including austenitics, for maximising physical and mechanical properties of welded joints in service, to modes of failure of welded joints, to applications of non-destructive testing, and to health and safety aspects of welding.

Countries outside the EEC

The European countries outside the European Community, reported by B Koch, Manager. The Danish Welding Institute, have limited economic resources. Industry in these countries tends to consist largely of small and medium sized enterprises. This gives the advantage of flexibility and adaptability, but the disadvantage that funds are limited so there are restricted resources to allocate to R & D. These organisations are therefore highly dependent on a well functioning technological service network of institutes, universities, *etc.* R & D is carried out in decreasing order of importance, in non-profit institutes, industrial laboratories and university laboratories. There are strong technical, economic and cultural ties between the Nordic countries—Denmark, Finland, Iceland, Norway and Sweden—and so the Nordic Council of Ministers has been set up to deal with questions of interest to all the countries. Nordic funding of research projects generally covers part (less than 50%) of expenditure and the remainder must be financed by national resources. This collaboration makes it possible to quadruple resources and to make use of the best equipment and personnel. An ad hoc committee of two experts from each Nordic country analysed the need for research and their list of priorities was as follows :

—automatic welding of large components in small series ;

—computer aided design and manufacture of welded structures ;

—mechanical properties of welded joints ;

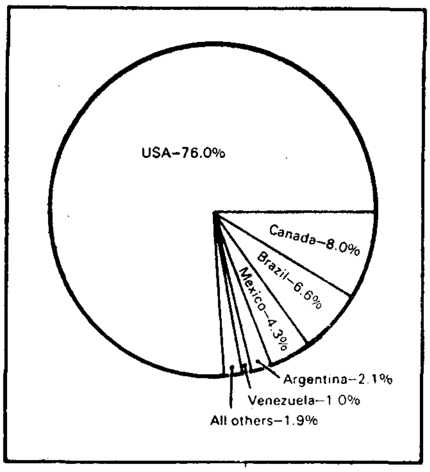
—a joint study tour of Japan.

The Far East

To avoid duplication of effort, and to promote mutual exchange of information and the effective application of the results of research, the Far Eastern countries have established their own research systems for conducting research on welding technology. Describing the set-up in the Far East, and concentrating particularly on Japan, China and Australia, Professor T. Kobayashi, Tohoku University, Sendai, Japan turned first to Japan. In this country there is no public research institute that undertakes research from the fundamentals through to development, but research is conducted almost independently in institutes of universities, related public organisations and enterprises. Osaka University is the most prominent in welding research, and embodies the Welding Research Institute and the Department of Welding Engineering. The former was established in 1972 for the nation's joint use by the Science Council of Japan. About 2000 graduates have passed through the Department of Welding Engineering since it was established in 1944 and it has eight chairs. Besides Osaka University, there are some 20 national and public universities having chairs in welding in related course such as metallurgy, machinery and structures. Welding research is also conducted by a number of public bodies, and by a variety of industrial enterprises. There tends to be some duplication of effort because of the independent basis of industrial research, but it is felt that there are many advantages through the competitive element involved.

Research on welding technology has expanded rapidly in the People's Republic of China since the state was established in 1949. Welding research began not only in the existing Qin Hua University, Beijin, but also in newly established universities, and today special welding organisations have been provided in ten or so universities for education and research. For example, in the Department of Materials Science and Engineering of Shanghai, Jiao Tong University there is a welding speciality which has six professors and associate professors and accepts 40 to 50 student each year. The Harbin Research Institute of Welding was established in 1957. Here basic rearch and applications development are carried out and the Institute is also conducting trial manufacture of large capacity friction welding machines and welding consumables. Some 400 people are on the staff, making it the largest such Institute in the Far East. More than 20 industrial organisations also have their own welding research departments.

In Australia there is no centralised welding research facility, but the Australian Welding Research Association was established in the early 60s to foster welding research effort in the country's universities and institutes, and there are now a number of valuable welding research programmes being undertaken. Organisations undertaking welding research include universities ; government, semi-government and statutory authorities ; and industry, particularly steel companies and welding equipment and consumables suppliers. The AWRA has a Project Panel System to coordinate the independent research and to assist in effective dissemination of information.

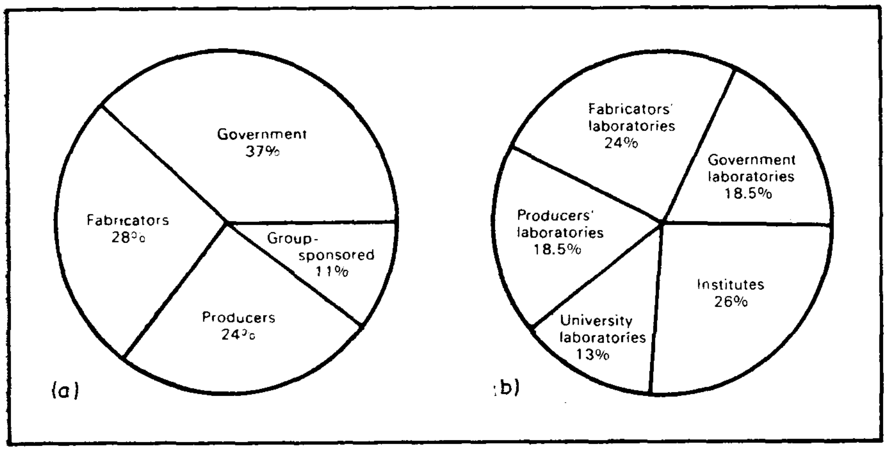


2. Welding activity in the Western Hemisphere.

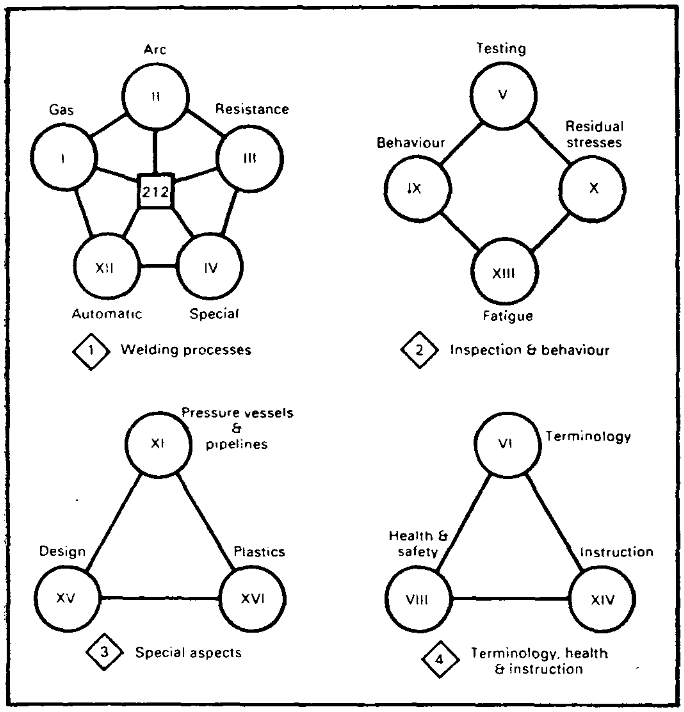
The Western Hemisphere

Turning to the Western Hemisphere, taken to include North and South America, Central America and the Caribbean islands, R. D. Thomas, Jr, President R. D. Thomas Inc, Narberth PA, USA, commenced by taking a variety of economic statistics and combining them to produce a welding activity index (Fig. 2). Almost 85% of the welding activity in the Western Hemisphere is found in the United States and Canada combined, although the relative standing of the country's commitments to welding research may differ from that set out in Fig. 2. The sources of research funds, and where they are spent are summarised in Fig. 3. In most countries in the Western Hemisphere where there are capitalist economies, resources are channelled in the direction likely to produce the greatest return on the investment. In the private sector, industries conduct welding research largely to promote their competitive position in the market place. Fabricators seek increased productivity and improved quality, suppliers of equipment and consumables work to develop new products and new processes. Both are motivated by competition, and there tends to be rapid implementation of the results of research if the potential return is high. However, there tends to be considerable duplication of effort, and research motivated by competition is frequently found lacking in depth because it is application oriented rather than scientifically directed. In the US the lack of depth of industrial research is offset by work done in universities, where the research activities are a by-product of the training of engineers and scientists. But even in the universities there is competition for funding, and guidance on research direction is not always adequate.

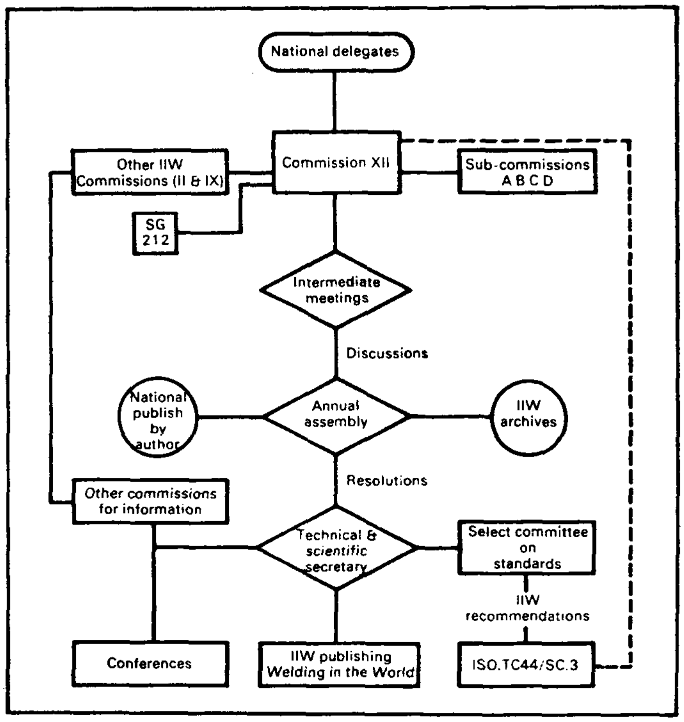
National governments are fre- major research efforts on projects quently the source of funding for of national relevance. For example, in Canada, where a large area of the country is subject to extremely low temperatures and energy resources in the Arctic regions must be extracted by welded structures and pipelines, government funding has been put into welding research projects to improve the toughness of joints subject to low temperature. In the US projects relating to energy self-sufficiency have been heavily funded by the government. In Latin America there are large state-owned organisations dependent on welding research. For instance in Argentina and Brazil the nuclear power companies support a considerable amount of welding research. In Mexico, the state-owned petroleum industry conducts its own research on welding. The annual level of funding is estimated to be greater than $50M in the US, $7M in Canada and less than $1M in Latin America.



3. Welding research funding in the United States : a) Sources of funds ; b) Expenditure of funds.



4. Grouping of IIW Commissions.



5. Schematic operation of IIW Commission XII.

A conference in April 1983 identified the following US priority categories for welding research :

Needs and opportunities

1. Productivity, automation, process control ;
2. Microstructure evolution and solidification ;
3. Advanced processes development ;
4. Transport processes, measurement and modelling ;
5. Fitness for purpose.

Coordinated activities

1. Fitness for purpose ;
2. Productivity, automation process control ;
3. Codes, standards, specifications and regulation ;
4. Advanced processes development ;
5. NDE, quality control and inspection.

Mr Thomas explained how this conference had led to the formation of the Welding Technology Applications Center (AWTAC), and touched upon the establishment of the Edison Welding Institute in Columbus, Ohio.

THE WORK OF THE IIW COMMISSIONS

The work of the IIW Commissions was described under four group headings, see Fig. 4. The work of each commission is at the discretion of the Chairman who is elected for a period of five years and is responsible for the progress of work on a programme drawn up each year from contributions supplied by national delegates to his commission from 38 member societies of the IIW. The Commissions differ slightly in their operation, but the essential sequence of activities is as stylised in Fig. 5.

Group 1—Processes, welding equipment and consumables

The group 1 Commissions are :

I Joining, cutting and surfacing by thermal processes ;

II Arc welding ;

III Resistance welding and related welding processes ;

IV Special welding processes ;

XII Flux and gas shielded electric welding processes ;

Study Group 212—Physics of welding.

The report on this group was prepared by Dr A A Smith. Chairman, Commission XII, Consultant, The Welding Institute, UK.

Commission I

A study is being made of fluxes and fillers used in soldering, and a separate group is examining reports on conventional and vacuum brazing. Aspects of thermal spraying and surfacing under study include various methods of testing bonding strength and homogeneity of coatings, and different methods of surfacing.

A booklet has been prepared based on numerous reports on the improved productivity obtained by the use of mechanised thermal cutting. Reports on design of nozzles and blow pipes for oxycutting have included a special study on the measurement of noise emissions. This has been referred to the ISO. In a current study of the characteristics of flame cut surfaces, an attempt is being made to classify important criteria such as 'cut surface flatness' and 'top edge.'

Commission II

Work has continued on the constitution of weld metals, and factors controlling development of microstructure and the role of inclusions have been reviewed. Responses from 23 laboratories regarding oxygen and nitrogen analysis have shown that no standards exist for sampling and analysis of weld metals which have heterogeneous distributions.

Methods for sampling and analysing weld metal hydrogen content have been studied for many years and formed the basis for ISO standard 3690. Chromatographic analysis methods have been accepted as alternatives over mercury.

An IIW method for determination of ferrite number in austenitic weld metals has been accepted, and work is also in hand to devise a simple international classification scheme for covered electrodes.

Commission III

This Commission covers a wide range of resistance and related welding processes such as flash, MIAB and friction welding. From a study of data from many countries it is hoped to understand the factors which affect growth and formation of the weld nugget and thus contribute to weld quality. Papers have been published on industrial problems such as electrode life and the effects on welding behaviour, and recommendations have been made to international bodies. A code of practice is being drawn up on embossed projection welding of mild steel, and a recommendation on measurement of hardness of welds is at present in ISO for consideration. There is growing interest in weld bonding, and the importance of overlap dimensions and type of adhesive has been studied.

Work on flash welding has included welding coil in steel mills and gas pipelines in arctic conditions.

Information on friction welding is being collated to prepare an IIW recommended procedure for basic component types.

Commission IV

This Commission studies electron beam, laser and plasma welding. A cooperative study involving ten research institutes and industrial laboratories has been completed, in which welds on a standard Al-Zn-Mg alloy were made at the same beam power and welding speed. This has shown that more work is necessary to characterise the electron beam and to develop experimental methods to measure the important parameters. Similar work is underway for laser welding. Beneficial effects of beam oscillation have been reported for welding thicker sections. Future work includes a study on heavy section EB welding, properties of and problems in using high power beams, and a study of the interaction of these beams with a workpiece.

Commission XII

Submerged arc, electroslag, MIG and TIG welding are studied by this commission, together with the power sources and control systems necessary for automatic and robotic applications. The long standing work programme has been directed to investigating complex slag/metal reactions, and it is hoped to develop a method of pre-calculating weld metal composition from a knowledge of the filler wire/flux/parent plate/ welding parameter combination.

To support the standardisation work of the Commission, a cooperative study has been undertaken by eight countries to classify shielding gases in terms of their oxidation potential and a ternary scheme has been published for argon-CO_2-O_2 mixtures.

A survey is underway on the characteristics important in selecting suitable power sources for robotic applications, including ignition of TIG and MIG arcs, reproducibility of output, programming and rating, and thermal aspects. Another survey is being conducted on MIG welding guns and wire feeders.

Stydy Group 212

A result of the Group's work on arc physics and other theoretical aspects of welding has been the production of a manual on 'Welding physics'. The Group's work covers topics including high speed rotating MIG arcs, mathematical modelling of heat transfer in the arc, a system for data acquisition in arc welding, analysis of the motion of covered electrodes, and metal transfer in MIG welding.

Group 2—Metallurgy, performance and inspection

The work of the Commissions in this group, reported by R.V Salkin, R & D Manager, Cockerill Mechanical Industries, Seraing, Belgium, is generally directed at gaining a better understanding and control of the reliability of weldments. The four Commissions are :

V Testing, measurement and control of welds ;

IX Behaviour of materials subjected to welding ;

X Residual stresses and stress relieving, brittle fracture ;

XIII Fatigue of welded components and structures.

Commission V

Over the years the Commission has drawn up and disseminated guidelines for reliable inspection procedures, good testing practice and quality assurance management behaviour. Reference radiographs and calibration procedures have been prepared to ensure uniformity of practice and aid data interpretation.

More recently, the Commission has become involved in studying austenitic weld inspection procedures and in developing strategies for sizing and characterising defects so that inspection data are compatible with the quantitative predictions of defect significance of fracture mechanics. A definition of quality classes for arc welded joints has been completed, and a QA manual to assist management decisions.

In future a major interest of the Commissions will be in the application of NDT technology to specific weld inspection problems rather than concentration on the inspection techniques themselves.

Commission IX

This Commission is the metallurgical body of the IIW, directed to improving understanding of welding metallurgy and to developing methods of testing weldability and to giving guidance on welding different types of metals. In the past five years, with the stimulus of the recession, work has been directed towards safer, less expensive and more sophisticated uses of steels and alloys of improved qualities.

In recent years the main problems investigated have been assessment of the cold cracking sensitivity of C-Mn and low alloy steels, the significance of underbead hardness and of carbon equivalent, analysis of stress relief cracking susceptibility, the mechanism of microstructure formation in weld metal, with its terminology and quantification, and the influence of microalloying elements. A draft standard has been prepared on implant testing to evaluate cold cracking susceptibility.

In preparing guidance on welding a range of materials, work is in progress dealing with low temperature steels, pipeline low carbon steels, austenitic ferritic steels, and dissimilar materials.

Commission X

Five working bodies are operating in the following areas :

—significance of defects with regard to brittle fracture ;

—fracture mechanics theory ;

—probabilistic fracture mechanics ;

—numerical analysis of stresses, strain and other effects produced by welding ;

—experimental methods of measuring stresses, strain and displacement.

The Commission aims to develop a consensus among the member societies of IIW on the use of fracture theories in the safety of welded construction, to clarify the effects of stress relief treatments, and to analyse the features of crack initiation and crack propagation in weldments.

Possible use of elastic-plastic fracture mechanics in fracture control of welded steel structures has been under consideration of about three years. A questionnaire has been undertaken to ascertain the use made of fracture mechanics, including elastic-plastic, for control of welded structures.

Study of fracture toughness testing techniques has covered several aspects including comparison of methods to measure CTOD and J values, use of ultrasonics to detect the onset of stable tearing, and fracture testing of welded joints by fatigue loading at low temperature.

Regarding residual stresses, restraint and distortion, areas covered have included calculation of deformation and residual stresses in different configurations, comparison of measurement of residual stresses and the influence of residual stresses on the stability of welded constructions.

The Commission is also concerned with other aspects of fracture including interpretation of wide plate test results, and the degradation of toughness caused by distributed deformation or distributed cracking.

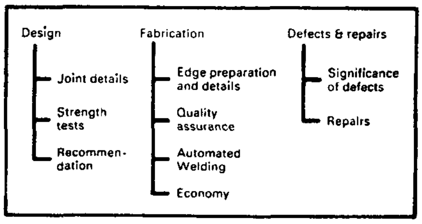
Commission XIII

The Commission works on collection of test results and their practical use for dimensioning of welded structures and test methods applicable to welded assemblies. It issues recommendations on ways to minimise faigue failures in welded assemblies, by use of fatigue design curves, by evaluation of the significance of defects on fatigue crack initiation, by analysis of effects of microstructure of stress states on crack propagation, and by a survey of existing codes and regulations.

For several years the Commission has maintained a permanent international enquiry on cases of fatigue fracture of welded structures, ranging from a child's folding bicycle to the Alexander Kielland failure.

Group 3—Design and strength of welded joints

Work in this group was reported by Dr D K Feder, Chairman of Commission XV, Chief Engineer, Structural Design, Krupp Industrie Technik GmbH, Germany. The group comprises Commissions :



6. Main topics, related to welded joints, covered by Group 3 of the IIW.

XI Pressure vessels, boilers and pipelines ;

XV Fundamentals of design and fabrication for welding ;

XVI Welding of plastics.

Because of the variety of interest within the Commissions, Dr Feder reported their activities divided into topics of interest, see Fig. 6.

Design

Commission XI has produced a document on welded connections for pressure vessels, together with a suitability grading, and Commission XV has embarked on a similar project. The aim is to provide a general catalogue of recommended weld details with indications of their respective advantages regarding strengths, manufacture, inspection, *etc.*

Stress analysis of welded joints is a continuing subject of study, and theoretical investigation of stress concentrations at notches is assigned great importance because of notch effects on fatigue strength and toughness. Stresses in welded joints are governed not only by the shape of the joint itself but also by the overall geometrical conditions in its vicinity. Hence studies of special configurations such as nozzles in pressure vessels or shell to bottom plate fillets in oil storage tanks have been undertaken.

For fatigue loaded joints, collecting and comparing test results is an absolute necessity, and at each annual assembly of the IIW test results from laboratories from all over the world are presented. Commission XVI has listed 'testing of welded joints' as one of the priority subjects for its future work. Similarly, the Select Committee for Aluminium has stated its intention to work on recommendations on test specimen forms and methods for the tensile test, the bend test, and fatigue testing of aluminium alloys. The mechanical properties of underwater welded joints are also an intended topic for future study.

Information on failures is also exchanged. although it is frequently limited by restrictions on confidentiality, but examples collected in recent years are about to be published in a third volume of an instructive collection of case studies.

Several documents have been produced on the design and calculation of tubular joints, and a subgroup is working on design recommendations for fatigue loaded tubular joints.

Fabrication

A consensus has been reached on edge preparation and detailing of joints and so these topics, except for special welding processes, are no longer under discussion.

On quality assurance, the required quality level, and the acceptability of weld defects rest with the engineer, who knows the function of the structure and the stress conditions. A major problem is to define different quality classes, since for many applications a relatively low quality can be quite sufficient. In Commission XV efforts to define quality levels date back more than 10 years. However, it seems that the requirements of different fields of application of welding vary too much to make possible a uniform classification scheme. Commission XV in cooperation with Commission XII, intends to give limits for acceptable defects in welded joints or fatigue loaded structures, when enough research results have become available.

To achieve economy in automated welding it may be that some joint types will have to be modified to adapt them to automated methods, or that automated weldability will become an additional criterion in judging the relative merits of different joint types. The Commissions are holding a watching brief on developments in this area.

Defects and repairs

The first step in evaluating the significance of defects consists in describing and quantifying them, which is the domain of Commission V. But to be able to make quantitative predictions on the influence of a defect with a certain shape and size it is necessary to test welded joints known to contain defects of a certain shape and size. Commissions X and XII have each taken a part in developing ways and means for simulation of defects in test specimens. Reports on fatigue tests on specimens with defined defects have laid the first foundations for evaluating the quantitative influence of defects on fatigue strengths.

A sub-commission is drafting recommendations on repair welding.

Group 4—Instruction, health, standardisation, documentation and terminology

The activities of the group were reported by Professor P Stular, Director, Welding Institute, Ljubljana, Yugoslavia. The Commission in the group are :

VI Terminology ;

VIII Health and safety ;

XIV Welding instruction ;

Study Group—Scientific and technical information ;

Select Committee—Standardisation

Commission XIV

The primary activities of the Commission are :

- —exchange of information on problems of welding and technical instruction ;
- —revision of syllabuses for welders, operators, technicians and engineers ;
- —revision of methods of teaching;
- —welder qualification.

Commission VIII

The first terms of reference of the Commission on its establishment in 1949, were to specify and standardise measures for protection of welders. In 1955, a handbook on safety and health was prepared, and is now available in a revised and extended edition.

The Commission's current activities are directed to preventing injury, to maintaining a high level of safety including consideration of possible long term effects, and to optimise the interrelation between the welder and his work.

Study Group on scientific and technical, information

The Group's present work programme includes :

1. Updating and revision of the international welding thesaurus;

2. Exchange of abstracts ;
3. Updating the general bibliography on welding ;
4. Consideration of possibilities for an IIW documentation centre ;
5. Monitoring new developments in scientific and technical information ;
6. Consideration of classification problems in welding—the views of IIW are being sought increasingly by other bodies, in particular ISO.

Select Committee on Standardisation

This Committee's main concerns are :

a. Liaison with IIW member societies ;
b. Liaison with the Commissions of the IIW to coordinate their activities related to standardisation ;
c. Transmission within the IIW of questions on standardisation coming from international organisations ;
d. Liaison between the IIW and international organisations dealing with standardisation, particularly the ISO and the IEC.

Commission VI

The main task of the Commission has been to publish several sections of the 'Multilingual collection' of terms for welding and allied processes' (MCT). The MCT is prepared in the 15 or more languages spoken by the individual delegations to the IIW, rather than in English, or English and French, so that other linguistic groups can find sufficient accurate synonyms to enable them to understand terms given in English.

The Commission is also considering classification of the 200 or so welding processes and their variants which have become established since the second world war.

'In summary' said M H Granjon, Technical and Scientific Secretariat, IIW France, 'the IIW has a very flexible structure, there is much interchange of information, and muc effort to put the information into application.'

COLLABORATION IN WELDING RESEARCH

This session considered a number of examples of collaborative welding research projects between countries and between university and industry. There has been a major international collaborative programme on steel research in Western Europe since 1955 under the sponsorship of the European Coal and Steel Community. The aims were to stimulate cooperative R & D, to enhance the competitiveness of the steel in dustry in Western Europe, to avoid duplication of effort, and to undertake large projects too costly for individual firms to finance. The programme is funded from the annual budget of the ECSC, and aid is provided on a contract basis to research projects undertaken in industry, research centres and universities. This aid represents 60% of the total research costs, the remaining 40% being provided by the beneficiary. Initially the programme was mainly concerned with raw materials and problems of iron and liquid steel production, but in recent years the greatest effort has concentrated on reducing production costs and improving quality and performance of the products.

Canada provided an example of a government initiative in technology transfer in welding. In 1978 the Canadian government authorised the creation of the Industrial Materials Research Institute, a division of the National Research Council of Canada. The mandate of the Institute is to assist Canadian industry technically, to increase productivity and to improve competitiveness. Technological barriers in vital industrial sectors have been identified and new approaches have been set up with managerial and technological aspects.

In the United States welding engineering education and research in the universities are reported to be experiencing a positive growth. There is an increased enrolment in welding related programmes at both graduate and undergraduate levels in all the engineering disciplines associated with assembly. This growth can be seen in the number of university faculties performing welding research. There are 91 faculty researchers, 126 students in Master of Science degree programmes 70 students in PhD programmes and 18 post-doctoral fellows involved in welding research in 17 universities. A total of around 58M per year support is given to the universities by industry and government as summarised in the Table.

In India, welding as a major university discipline can be traced back only about 15 years, even though it has been a principal fabrication technique within the country for several decades. To fill this gap, the Indian Institute of Technology, Madras set up a Metal Joining Laboratory to initiate research and postgraduate instructional programmes in this area. Collaboration between university and industry takes place through sponsored research programmes, through consultancy, through research projects for industrial personnel leading to postgraduate degrees, through support of university postgraduate research projects and through recognition of research contributions of industrial relevance by awards, fellowships, etc.

Industrial and Federal support for welding research in the USA

Welding research laboratories	Industrial, $K	Federal, $K	Total, $K
Ohio State University	800	700	1500
Colorado School of Mines	550	700	1250
Carnegie Mellon University	100	780	880
Univ of Illinois at Urbana	415	400	815
Massachusetts Inst of Tech	160	600	760
Lehigh University	300	350	650
Oregon Graduate Center	350	150	500
Rensselaer Polytechnic Inst	80	350	430
Univ of Wisconsin	140	110	250
Univ of California at Berkeley	5	200	205
University of Tennessee	120	80	200
Univ of Tulsa	20	115	135
Utah State University	75	30	105
Univ of Alabama at Birmingham	25	65	90
Univ of Pittsburgh	45	25	70
Univ of Illinois at Chicago	80	0	80
Clarkson University	55	0	55
Total ($K)	3320	4655	7975
Total (%)	42	58	100

In Poland there are 10 universities carrying out welding research collaboration with various branches of industry and factories producing welded structures. Cooperation between technical universities and industry has led to solution of a number of welding problems important to the economy of the country. These included work on processing of ship steel plates of higher tensile strengths and appropriate welding technology, and development of the technology of explosive welding of joints for the chemical and ship building industries. The Polish Institute of Welding coordinates scientific collaboration between industry and technical universities in welding.

RESEARCH DIRECTIONS IN WELDED CONSTRUCTION

This session summarised present and future developments in a wide range of fabrication activities. In pipeline construction, present welding research effort is directed towards increasing the safety of the line, to ensure a long operational life without failure in even the most severe environmental conditions, and to optimising the costs of installation, operation and maintenance. Hence, specific topics for future R & D include :

- i Improved weldability of modern pipeline steels ;
- ii Development of welded steels of higher strengths and toughness ;
- iii Development of NDT techniques for detecting, characterising and sizing weld defects;
- iv Development of automatic welding systems.

In present offshore structures, the steels used conventionally such as NVE-36 or BS 4360-50D, have given satisfactory performance, but experience has indicated that steel for future use further north, where the environment is more hostile and the water depth greater, will require improved characteristics. Attention has focused on weldability and toughness, resulting in stricter requirements including a maximum HAZ hardness of 325HV5, a requirement which generally cannot be achieved using the conventional steel grades mentioned above. In the course of research aimed at improving steel properties, carbon content has been reduced to a maximum of 0.12%, but otherwise chemistry as regards manganese, silicon and microalloying elements has not deviated from conventional practice. Impurity contents are low, and to meet tensile requirements small additions of Cu and Ni have been accepted. During fabrication of these steels, problems of low toughness in coarse grained HAZ have been encountered. Recent research has shown that the occurrence of localised brittle zones can be reduced or avoided by altering the chemical composition and thereby the austenitic decomposition, but there is a clear need for further research.

Research and development on nuclear energy projects in the UK has been applied to gas cooled, pressurised water and breeder reactor systems. Validation work on parent materials and weldments in relevant materials has been carried out for all systems. Materials problems have been encountered in type 316 weldments, in development of a chemical specification for nitric acid resistant grades of austenitic steel, in variable TIG weld penetration with austenitic steels in austenitic/ferritic joints, and in hydrogen induced underclad cracking. There have been a number of developments in mechanisation of tube welding because of the number of joints required. The TIG process has normally been used and stationary arc rotating tube production lines have been set up. Orbital equipment has been developed for joints where the tubes cannot be rotated, and equipment available can weld tubes with clearance down to ~16 mm. Manufacture of steam generators for the AGR involved making 8.5M tube/spacer welds. A robotic system was developed, each unit consisting of two robots mounted on a tracked gantry. Special equipment has also been developed to cope with a variety of difficult repairs. For instance, for certain AGR stations equipment has been developed to replace flow restrictor ferrules on the feed water tubeplate. The equipment machines out the existing ferrule, and builds a weld round the hole which is machined to a spigot for tube/spigot welding. The replacement ferrule unit is positioned and welded by pulsed TIG, using an optical sensing feedback system fitted externally to the replacement ferule, which automatically controls penetration. After welding internal overfill is removed by machining.

In welded bridge construction microcracking in the toes of fillet welds is a particular problem. A cost effective method is required for testing fillet weld HAZs to permit optimisation of weld procedures. A two step impact test based on Charpy specimens is proposed.

Since the 70s energy crisis, the number of ships built throughout the world has fallen drastically, and the demand has been for different types of ship. Research in ship building in Japan has been tailored accordingly, and a fully automated shipyard is seen as the ultimate aim. Use of gas shielded arc welding processes has substantially increased, and this trend is expected to continue. There will be increasing application of robots, and it is expected that high energy density processes will also be used.

Welding research in the USA aerospace sector is influenced both by the nature of the product, which is low unit production, high unit cost, and by the organisation of the industry as a collection of private enterprises doing business primarily with the government. The principal technical factors are the need for high performance, which means keeping weight down and maintaining a high strength to weight ratio, reliability, and the need to withstand a hostile environment and rapid temperature changes. For high performance there will be more work on new materials and hence on new welding processes. To ensure satisfactory service in a hostile environment more work is needed on the significance of defects. Reduction of production costs at low volume will depend on developements in adaptive automation, in process sensing and process modelling.

In the aircraft industry, the main trends are :

a. A constant increase in engine sizes ;
b. Evolution in selection of materials towards higher creep resistance under more severe service conditions. This has led to a shift from Al or Mg alloys to martensitic stainless steels and titanium or to the adoption of precipitation hardening nickel alloys ;
c. Advances in joining processes have been less marked than in materials technology. The most used processes are TIG, EB, laser, and friction welding and brazing or duffusion brazing ;
d. Non-destructive testing methods have become more sophisticated, but use of fracture mechanics methods should allow a number of defects to be accepted. Research is centered on a better control of surface conditions, a better control of weld heat input, on developments in diffusion brazing of certain heat resisting alloys.

RESEARCH DIRECTIONS IN WELDING PROCESSES

This session covered developments in high energy processes, automation, microjoining, and health and safety.

Research on electron beam welding is concerned with improved characterisation of the beam, improved process analysis, better definition of material requirements for the process, and development of mechanised welding equipment. There will be improvements in quality control and in specific design for EB welding, and wider use of the technique at atmospheric pressure. In laser welding there will be development of measuring techniques to improve beam characterisation, development of high power equipment, improved beam stability, better automation, and development of techniques involving use of filler wire.

Benefits to be sought from automated welding range from an immediate improvement in production rates and reduced repair costs to a more fundamental exploitation technology approaches in fabrication. Application of CAD/CAM/CIM is of particular interest, but welding can only be included once it can be adaptively controlled to a higher level than at present. With most robots now operating on open loop there is a need for better seam tracking and feed back systems. With manual welding techniques forming the basis of much current fabrication practice, extensive changes are required in welding equipment and production approaches. There is a need for new power sources, modular design robots, and for a problem oriented control language.

The recent dramatic expansion in use and capability of electronic devices has been facilitated by developments in porduction techniques.

Modern electronic circuits contain many joints which have to be made reliably, economically and without degrading the circuit components. Virtually all the main welding techniques are employed, with the exception of the heavy arc welding processes and explosive welding. Brazing, soldering and adhesive bonding are also widely used. As circuits have become more complex bond pad size has been reduced, and optimisation of the ball/wedge wire bonding technique has made it possible to bond 25μm wires to pads less than 50μm square. Automation of device interconnection is widespread, and has probably proceeded as far as possible with available machines. Further increases in productivity are likely to depend on use of techniques such as tape automated bonding. Changes in materials, such as from Si to Group III-IV materials for technical reasons, or from noble metals to Al or Cu for economics, are giving rise to a continuing need to modify and develop joining techniques. There is also a great need to develop in-process quality control techniques rather than batch destructive testing which is currently employed.

Under future research needs in welding health and safety, the topic considered was risk in the stainless steel welding sector. Recent developments in study of the biological activity of welding fumes have tended to indicate Cr and Ni as potential carcinogens. At present there is no experimental information concerning either the relative carcinogenic potency of stainless steel welding fumes from each of the different welding processes, or the specific toxicity per inhaled dose of fume. However, it behoves the welding industry to take steps which will permit orderly management of risk by considering automation, alternative technologies, worker protection, *etc.*

WELDING RESEARCH AND OTHER DISCIPLINES

The final technical session, on the interrelation of welding research with other disciplines, began with a consideration of the challenge of theoretical research in welding. What is meant by welding theory ? In physics it can include study of heat flow in electrodes, arc columns, and workpieces ; mass flow and metal transfer; flow of electric charge, and interaction of charged particles in arc plasmas ; surface properties ; and electromagnetism. Chemical aspects include metal/gas interactions ; slag reactions ; and embrittlement caused by solution of gases ; while metallurgy is particularly concerned in solidification and solid state cracking. Understanding of the electric arc has developed only slowly, for instance the mechanism of the non-thermionic type of cathode, such as that which forms on aluminium, copper or steel electrodes, has proved to be particularly intractable. Understanding has been advanced recently by study involving scanning electron microscope examination of cathode surfaces after arcing in the nanosecond to microsecond range. There has also been progress in applying analysis of the dynamics of falling drops to metal transfer in MIG/MAG welding.

Welding engineering is a multidisplinary technology, and most of the problems are non-linear and transient and must be considered under extreme conditions such as high temperature or high vacuum. This tends to limit the application of computer and numerical analysis techniques only to simple cases but nonetheless the computer is seen as having great potential as a research tool. To achieve meaningful research results the gap between real phenomena and mathematical models must be bridged through closer co-operation between experimentalists, theoreticians and analysis. Problems which have already been tackled include analysis of welding stress and strains by finite element methods, study of the convective heat flow in a molten pool, scattering of high power electron beams, and diffusion of hydrogen in metals.

Because properties related to structural integrity are more crucial in the heat affected zone (HAZ) than in the base metal, the effect of welding research on steel composition development has been to focus on improvement of HAZ properties, that is in weldability of the steel. Therefore, for linepipe which is welded with a high cooling rate, ultra low carbon (0.02%) steel has been developed. Weldability in a narrow sense represents resistance to cold cracking, and the weldability of C-Mn steel can be described well by the IIW carbon equivalent formula. However, when carbon content is reduced and other alloying elements are added a different expression for carbon equivalent is required. Degradation of HAZ toughness can be minimised by reducing carbon equivalent and solute nitrogen. The CE can be reduced by controlled rolling or use of a thermomechanical control process. Toughness degradation can also be reduced by grain refining of HAZ microstructure by pinning austenite grain boundaries and enhancement of intragranular ferrite nucleation from dispersed particles. Based on this concept, a ship steel has been developed which employs TMCP to reduce CE and utilises TiN-MnS complex inclusions for grain boundary pinning and ferrite nucleation.

Welding research is now having a marked impact on specifications and standards development. Originally standards simply reflected industrial practice with research playing a secondary role, but the much wider application of welding and a new generation of structural concepts have created a pressing need for better engineering comprehension of phenomena associated with welding. Specific achievements of welding research in specifications and standards include :

—the research supported specification approach of the Paton Institute in the USSR to certification of fluxes ;

—research by the DVS in submerged arc fluxes, eventually introduced into the DIN specification ;

—innovative modifications introduced into specifications resulting from extensive studies of fatigue in the UK and USA ;

—after extensive research at The Welding Institute, UK the concept of fitness for purpose has been embodied in BS PD 6493.

In summary research must be geared to industrial priorities, and standards provide the link between research and practical application.

The concluding talk in the session considered how research can be directed in appropriate technology for developing countries. The concept of 'appropriate' arose when it was found that some aid programmes to developing countries were effective, others proved counter-productive. Many factors regarding a society, its economy and its people must be considered when selecting appropriate technology. Suggested topics for consideration by the IIW were :

1. What are the current and future needs for each less developed country for the various welding technologies ?

2. What resources of materials, equipment and manpower does each less developed country have to meet its welding needs ? What steps can be taken to improve the quantity and quality of the welding skills available in design manufacture and inspection ?

* * *

A suitably outward looking conclusion to a comprehensive review of world welding research activity.