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CURRENT ADVANCES IN WELDING TECHNOLOGY

ACHAR* D.R.G.

ABSTRACT

An overview of the trends in welding science and technology is projected after taking cognizance of the current state-of-art in the world over. The situation in the Indian welding industries in relation to the global scenario is discussed. Several developments are described relating to the latest modifications/changes in welding processes, consumables and technology. Some of the novel approaches of joining advanced materials are highlighted. The growing significance of basic welding research to provide the much needed science base to welding technology is elucidated. Finally, what needs to be done by the Indian fabrication industry to achieve competitive edge over others in the region in the manufacturing sector is addressed.

KEY WORDS

Welding technology - future trends - process advances - futuristic materials - technology innovations -welding science research.

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* Head, Materials Joining Laboratory, Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai, India.
Email: achar@iitm.ac.in

INTRODUCTION

The presentation is intended to highlight the current status of various facets of welding science and technology in the world over vis-à-vis the Indian situation. Welding plays a dominant role in the manufacturing industry, hence, growth of the manufacturing industry of a country can be gauged through the growth of the welding industry. There are several parameters used to gauge the growth of the welding industry. One of the strong parameter is to look at the steel consumption of a country. The world steel consumption increased from about 850 Mt in 2000 to almost a billion Mt in 2005, the corresponding values for India are 27 Mt to 35 Mt (expected) showing about 8% per year growth, while PR China records about 15% growth and stands today at a consumption level of about 23% world steel production [1, 2]. Since, in recent times major manufacturing activities involving welding have shifted to China, India and other countries in this region. India, with all the high level research potential, technically trained human resources availability and leadership in IT sector, should be able to match with the manufacturing potential of China in the immediate future.

STATUS AND DEVELOPMENTS IN JOINING / WELDING PROCESSES

The evolution of various welding processes over about a century is shown in **Fig. 1**. It is clear that not much development has happened, in terms of increase of energy density amongst the fusion welding processes, since the advent of laser beam systems. Welding with covered electrodes is on the decline in the industrialized countries. In Japan and Europe, the consumption of covered electrodes has fallen to half of all the consumable that are used. The proportions of welding using covered electrodes will stabilize at a level of 25% during the coming decade [1, 2]. In India, it is still occupying a commanding position of more than 60%. It can come down only with the increasing usage of more automated/mechanized welding adopted in the industries. The MIG/MAG welding, developed in 1970s has been firmly established and has overtaken welding with covered electrodes. The productivity of MIG/MAG welding can be increased significantly if mixed shielding gases are used and this is currently attracting a great deal of attention worldwide. In recent times there has been some revival of MIG-Plasma welding.

Fluxcored Welding Growth

Amongst the arc welding processes, it is the flux cored arc welding process which is becoming the bulk fabricating process. Probably, it will soon be taking lion's share of stick electrode welding in India. This is in view of its wide applications in ship building and offshore platforms fabrication in recent times. It is proving competitive to SAW in other heavy engineering fabrications as well. Further, in recent times it has expanded to include stainless and alloy steel fabrications also.

The MIG/MAG welding with solid wire has stabilized in the world over with the exception of the USA, where the proportion of welding with tubular wire is increasing markedly. Tubular wire is a filler material that has been established during the 1980s, though the degree of usage varies from country to country. More tubular wire is used in Japan and in the USA (about 15%) whilst in Europe, the corresponding figure is only 4%. In Japan tubular wire has replaced covered electrodes in recent years, particularly in the ship building industry. The applications of flux cored wires have been on the rise in the Indian fabrication in the power plant and ship building components. The one drawback in its usage is it causes a fair amount of spatter. Attempts are now being made to remedy this with pulsed welding. The development of power sources (thyristor, inverter and transistor controlled) has facilitated the adjustment of welding parameters and made it possible to develop synergic MIG/MAG welding with pulse frequency. Now, the use of tubular wire with gas shielding is increasing, whilst its use without gas shield is declining.

Electron Beam Welding – Bulk Fabrication

Electron beam welding (EBW) is universally recognized as a high-energy-density beam process and is well know for its ability to produce a higher welding speed, lower heat input and greater depth-to-width ratio fusion zone than most other methods of welding [4]. A whole gamut of process control developments involving joint tracking, on-line ultrasonic monitoring of the weld joint and computer controlled interfacing have also been achieved [1, 3, and 4]. Although, widely recognized for its capacity to provide these desirable weld characteristics when applied to work pieces located in vacuum, it is not generally well known that the process can also be applied to work placed outside of vacuum. If the welding is done in the atmosphere, rather than in vacuum, the electrons in an EB are ‘scattered’ by the interactions with the ambient air molecules. Therefore, when employing the EB process directly in air, fairly narrow welds can be obtained (when desired) if a work distance around 9.5 mm is used, while at larger work distances, increasingly wider welds will be produced.

As such, the ‘non-vacuum mode’ of electron beam welding (EBW-NV) has been used to successfully produce millions of car frame parts. The Welding Institute has, for example, conducted welding tests on copper lids with t = 75 mm for containers for nuclear waste on behalf of Sweden and have shown them to be nuclear leakage safe. It is also interesting to note that a vacuum chamber with a mobile, CNC controlled EB cannon has been installed in Japan to weld pressure vessels with a maximum length of 20m and a diameter 4m. This implies that EB welding which was primarily confined to welding of small and sophisticated components has moved over to the shop floor for large structures for pressure vessels and chemical plants. In India they have been used in the manufacturing and repair of various aerospace and nuclear components like engine blades and fuel end cap sealing. The major obstacle faced in the large scale adoption of this high energy density process in the country is high investment and maintenance cost, in addition to the problem of getting spares since, most of these equipments are imported. The one of the manufacturer of this system in the country is the Bhabha Atomic Energy Center.

All- Pervading Laser Beam Processes

The CO_2 laser which until now has been primarily used for cutting is being used increasingly for welding, first and foremost, in the automotive industry. Despite its high initial cost, laser beam welding is being recognized as the best method for many production lines. In Germany, for example, one-third of the BMW automobile is said to be made up of tailored welded blanks. Audi and VW are using Nd -YAG lasers with robotics. Volkswagen is switching to nearly 100% continuous root welding on all new cars. The big question remains: can resistance spot welding be replaced by laser beam welding? Volvo is doing some of this. Already, the Daimler Benz of Germany is leading in the application of lasers in its car manufacturing. In Japan, Mitsubishi has done some work in this area. But so far, there are no complete replacements.

Of the already existing high energy density processes, laser beam process has been envisaged to become practically all pervading heat source for cutting, welding, heat treating, surfacing, etching and many more. Its applications stretching to all types of component productions from heart pacemakers, where welds have to be realized within an mm of the circuitry and batteries, to automobile industry. In fact, in the case of the latter it is expected to become a dominant process throughout the world. Further, in recent times it is being increasingly introduced not only in the sheet metal work but as well in heavy plate fabrications involved in submarines, ship building and offshore platforms [1.3.4]. The other developmental trends in this process are;

a) Laser-MIG hybrid system to achieve high depth of penetration and right weld reinforcement particularly for thick plate welding [4, 5] (**Fig. 2, 3**)
b) Multi beam and Miniaturization of the systems
c) 3-D Laser systems
d) Application of dual beams to counter peak hardness in hardenable materials.

Innovative Welding Process-Friction Stir Welding

Development of friction stir welding (**Fig. 4**), by the welding Institute (U.K) in the last segment of the last century has taken the welding industry by storm. It also ended a long lull in the welding process evolution. The weld is formed by plunging a rotating shouldered tool-with a pin length slightly less than the weld depth required-into the firmly clamped work piece until the tool shoulder is in intimate contact with the work surface. The tool is rotated at a certain peripheral speed and moved along the joint. When the tool is moved along the joint, the material is plasticized by the frictional heat of the front of the rotating probe and is transported behind the probe, thereby forming a weld. Only metals with fairly low melting temperatures, such as aluminium and copper have so far been successfully friction stir welded on production scales, due to the temperature durability of the tools (**Table 1**).

Friction Hydro Pillar processing (FHPP) is another version of Friction stir welding. It is thought to be of primary interest for repair work, but it may also be applicable for joining robust structures [1, 3]. FHPP involves rotating a rod which is joined by the heat generated by friction to the parent metal in a pre-drilled hole. It is estimated that a deep hole can be filled in 20 seconds. The first commercial FSW installation for joining aluminium ship panels of up to 6x16m was put into operation in Norway. DNV has approved the system for welding aluminum extrusions and panels intended for application in DNV-classed vessels. In addition to the attractive welding results, the friction stir welding process generates almost no heat distortion, thereby eliminating expensive straightening of the work piece. Tool size determines the weld size, welding speed and tool strength. The tool material determines the rate of friction heating, tool strength and working temperature, the later ultimately determining which material can be friction stir welded.

From a welding process stand point, the future scope for friction stir welding initially lies in the progress of the welding tool development. The tool technology is the heart of the friction stir welding process. In India there have been no reports of this process being adopted on a production scale.

Micro Joining

Advances in technology are often closely associated with the miniaturization of components. This decade is experiencing the phenomena at a dizzy speed. Cellular phones that are no bigger than the palm of an ordinary hand; medical devices that probe the inner recesses of the body; laptop computers that really are becoming too small for the lap; and there is more to come. None of these would be possible, however, without the technology for welding. In micro welding a variety of processes commonly used are the following: Lasers, GTA, plasma arc, resistance, soldering, brazing, induction furnace and ultrasonic. How to distinguish this type of joining from conventional ones?

There are no official definitions to the terms “micro joining or micro welding”. Some who are in this field define it as being within a certain current range, typically 0.5 to 50A for fusion processes others might limit it to parts of a certain thickness or diameter, typically 0.1 inch (2.5mm) and much less, down to 0.001 inch (0.025mm). Others will put a heat input limit on it. With the laser process, 10-100J is considered in the micro joining area. Weld force with resistance welding might be in the range of 100g to 70kg.

In future, the electronics industry relies heavily on micro joining and it is a multi-billion-dollar business. The growth of micro joining will be tied closely to the growth of electronics, especially in an automotive field [1, 3]. More and more of the operation of an automobile engine is controlled by electronics. The future might also bring about a combination of processes for a single type of application. “Take resistance welding and ultrasonic and put them together”, or “add forging pressure while laser welding”, combining processes can give some advantages.

DEVELOPMENT OF CONSUMABLES

Some of the special challenges facing the welding consumable manufacturers are the development of consumable for artic and offshore structures, super thermal power plant steels like P91, super alloys for turbine applications operating temperatures of 600-700 C, and for newer aerospace materials such as Al-Li alloys. Also, special welding consumables are required for hard facing and maintenance welding in thermal power plants, dissimilar metal welds and for special environments, such as underwater welding.

New types of stainless steels are being introduced to increase the service life of systems that contain corrosive media. New stainless steel consumable will be needed for nitrogen-strengthened stainless steels, duplex stainless steels and for metals used in cryogenic service.

Currently, the consumable industry is in a position to fairly predict weld deposit properties as functions of the weld composition, welding parameters and thermal experience. New expressions based on fundamental concepts are replacing the existing basicity index and carbon equivalent expressions. Equal property diagrams will be available to assist in welding consumable selection with changes in welding parameters or conditions, such as a change in heat input. Also, in the next decade, we could see the use of multiple consumable to achieve composite-type properties in multiple pass welding. By using alternating passes of different consumable, joints that produce both higher strength and toughness could be achieved.

TECHNOLOGY DEVELOPMENT TRENDS

The next generation could see a totally different type of commercial as well as fighter aircrafts - all welded ones, involving materials like aluminium-lithium alloys and alpha and alpha-beta titanium alloys. The welding processes actively investigated are newly developing Friction Stir welding, EB and LB welding processes. This opens up billions of dollars of welding business in the next decade and the Indian industry could as well get a share of this, if it gears up with some of these state-of the-art technologies.

Automobile sector is another area where there will be sea changes both in terms of materials and fabrication technologies used. Several aluminium based alloys as well as MMC's are tending to replace the steels. The steel manufacturers on the other hand, particularly the European and Japanese, are investing largely in a consortium approach to develop newer steels and cost competitive steel designs. All these are leading to extensive applications of multi head laser systems, a combination of welding and special adhesive bonding processes, use of friction stir welding, extensive welding of tailored blanks and total robotisation. All these beneficial innovations indeed make use of extensive automation, robotisation, opto-electronic seam tracking and advanced versions of CAD/CAM.

GROWTH OF ROBOTICS IN WELDING

In the coming decades there may not be any sphere of welding activity - from tractors to aircrafts - where robots may not be used, at least in some of the industrially advanced countries. The automotive industry surpasses all other manufacturers in comprehending the long term benefits of capital investment in robotics automation. Notably starting with welding applications, the major automakers in Europe were the first to apply external joint sensors to robotics arc welding and have installed large volumes of spot welding robots as early as in 1980s. The United States has been slow to embrace robotics automation. For instance, Japan, a country with 125 million people and a lower total gross national product than the U.S., has almost about million robots installed, while the U.S. has only about 100,000 [6].

In recent times, a relatively new application is the use of a computer with data-acquisition software and an analog-to-digital expansion board to collect data during welds. This equipment allows a welding engineer to monitor parameters such as current, voltage, and weld cooling rate, then, correlate the data to weld characteristics.

WELDING SCIENCE RESEARCH

In the field of welding technology, generally technological developments have outmatched the developments in their science base. This has been because the technological growth has been primarily driven by immediate industrial demands in all sectors - primary metal production, energy, chemical, oil and natural gases - in the first half of last century. However, in the last three to four decades stringent quality standards and high reliability with cost viability have been imposed on the welded structures. These requirements are forcing the welding technologists to look at weld failures like brittle fracture of oil platforms and pipe lines, lamellar tearing of heavy structurals, hot cracking / micro fissuring in nickel rich and aluminium alloys, in a more systematic and logical approach rather than on an ad-hoc basis. In reproducible quality control of weld properties, one has to address the complexities in understanding fusion welding processes as well as micro and macrostructural changes in the different regions of welded structures.

With the advent computational techniques, solutions to complex welding problems based on scientific principals are being evaluated. Reliable computer models of thermal cycles and temperature profiles across the weld are now possible to be predicted to determine the fusion zone geometry and heat affected zone profiles [7, 8]. Considerable progress has also been made in developing a quantitative understanding of various micro and macrostructural changes such as phase composition, phase stability over temperature fields [9, 10], grain and inclusion nature and structures for some simple alloys [11]. Today, it has been gradually possible to provide clear scientific explanations to several observed phenomena encountered in flame cutting, soldering, brazing, cold welding and some aspects of a few fusion welding processes. Developments in microelectronic and digital photography at phenomenally high exposure speeds as CCD and LCD cameras have enabled in capturing the physical transport processes of weld droplets in many fusion welding processes, thus paving way for better understanding of metal transfer mechanisms and the factors controlling them. So also, one is able to make fairly reliable predictions with regard to residual stresses and distortions through computational analysis of welded structures. In recent times, fuzzy logic and artificial neural network models have been successfully used in the process parameter optimizations and so also so in certain NDT evaluation of welds [12]. This knowledge base explosion can serve as a sound basis for the control of welding processes and, thus, greatly enhance the quality, reproducibility, reliability and serviceability of welded structures. In the last couple of decades the researchers in India in this field have also made significant contributions to this knowledge base expansion.

CHALLENGES IN JOINING / WELDING MODERN MATERIALS

The newer materials here include both metallic varieties relating to super alloys, refractory materials, Dispersion Strengthened Alloys (DSA's) and non-metallic ones like high temperature engineering ceramics, intermetallics, Metal Matrix Composites (MMC's), electronic materials and biomaterials. These newer class of materials developed / being developed extensively in the current decade are envisaged for applications in a wide range of critical industries, viz., energy related plants (nuclear, thermal, solid oxide fuel cells, etc.), aviation and space industries (aircraft components, gas turbine engines, space shuttle bodies), IT industries (computer chips), miniature thermal sensitive electronic switches, and automobile industries (all aluminium or aluminium based material cars). The welding engineer in the coming decades will face challenging tasks in joining between metal to metal, ceramic to ceramic, metal to ceramic, metal to MMC's, metal to intermetallics and the like [14]. These will pose problems on several fronts - joining process selection, metallurgical property changes and joint quality evaluation - in view of diverse physical, thermal, mechanical and metallurgical properties of these new classes of materials. In fact, successful commercial utilization of any new engineering material will largely depend upon its amenability for joining with itself and with other materials, without loosing its specific and special properties for which it has been developed. One can recall here the poor commercial exploitation of metallic glasses for engineering applications, because joining technology was not developed for them. A diverse range of joining technologies have been attempted and continue to be attempted by welding researchers in joining the aforementioned new range of materials.

In respect of high temperature refractory metallic materials, the high energy density processes are being increasingly used. With respect to the new range of aluminium-lithium alloys bearing scandium, which is threatening to replace the steel in the automobile industry (Opel Industries, Germany has already come out with an all aluminium car in the market) and also increasingly being thought of as the future aircraft material, the processes being assessed are superplastic forming, diffusion bonding and friction stir welding. When it comes to non-metallic materials, it is totally a different cup of tea. Several joining processes as listed below, which are being pursued to tackle the wide range problems faced in their joining to themselves and to other metallic or non-metallic materials.

1. Ceramic to Metal components: (Syalon 20 to Kovar, Aluminium to Copper, Boron Nitride, Silicium Carbide to Metals).
    - Mechanical Joining
    - Direct and Indirect Diffusion Bonding
    - Fusion Welding (EBW and LBW)
    - Friction welding(Conventional and Stir process)
    - Liquid / Solid phase bonding
2. Ceramic to Ceramic joints: (Alumina, Zirconia, Beryllia)
    - Mechanical fastening
    - EB and LB welding
    - Brazing in high purity inert atmosphere or in vacuum furnace
    - Soldering
3. Intermetallics - Metal joints: (Titanium aluminides, Nickel aluminides, Titanium borides to Super alloys)
    - Diffusion bonding (deformation diffusion bonding processes)
    - Transient liquid phase bonding
    - Creep isostatic pressing (CRISP)
    - Superplastic forming / bonding (SPF/DB)
    - Welding (EB, LB, Pulsed TIG, Plasma)
    - Friction welding
    - Flash butt welding
    - Brazing

CONCLUSIONS

There have been improvements and modifications in the conventional welding processes with the introduction of inverter based power sources, use of micro processors and state-of –the art sensors and tracking devices. Applications of high energy density processes like LASER and EB, Robotics and CAD/CAM in the areas like transportation systems, shipbuilding and other heavy engineering sector have been far below in comparison to some competitive manufacturing centres in Europe, China and Korea.

Welding research in the global scene has made monumental progress in recent decades, primarily in simulation and modeling. Various facets of welding technology ranging from thermal cycles, HAZs, microstructural changes, stress analysis to on-line NDT applications through application sound modeling techniques, fuzzy logic and neural network concepts. But still lot more seems to be required to translate many of these to shop floor engineering practices. Welding research in India, is carried out in many Indian Institutes of Technology's and in some leading Universities. Welding Research Institute in BHEL (Trichy), Indira Gandhi Centre for Atomic Research (Kalpakkam) and several other research centers have contributed significantly to the knowledge base. But, these have been fragmented, though excellent by themselves, primarily dealing with process effects on structure – property correlations, process adaptation and testing, but leading very little to new product developments.

There is an urgent need to establish a comprehensive and independent Manufacturing Research and Development. This should be able to address itself to design, materials, fabrication and testing in a product life cycle approach. A center devoted primarily to product developments, apart from, in conventional engineering in new vistas of MEMS, microelectronics and bio-medical engineering using nanotechnology. All these approached through a consortium approach from all concerned industries. Some of the immediate tasks identified are development of smoke controlled electrodes, solar energy based joining systems, offshore engineering systems. There is also a great need for development of under water technology.

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Table 1. Potential Applications of Friction Stir Welding Process [1, 3]

Applications

Industry	Applications
Aerospace	Airframes, fuel tanks, and attachment of special alloy skins
Automotive	Chassis, space frames, wheels, bulk carrier tanks.
Construction	Bridges, offshore accommodation units.
Beverage	Beer barrels.
Railway rolling stock	Wagon and coach chassis and coachwork for high-speed trains.
Refrigeration	Cryogenic pipes and heat exchangers.
Shipbuilding	Hulls, decks and internal structures for lightweight, energy-efficient high-speed ships.
Pressure vessels	Liquid gas containers.

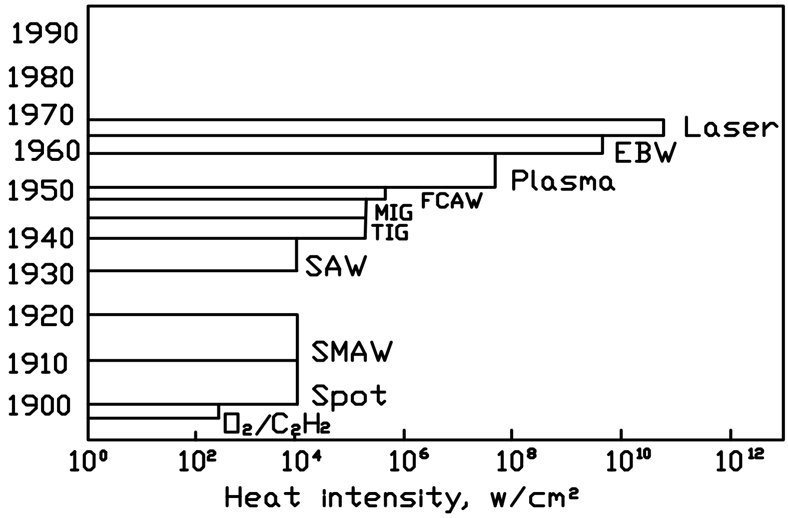

Fig.1. Growth in welding processes

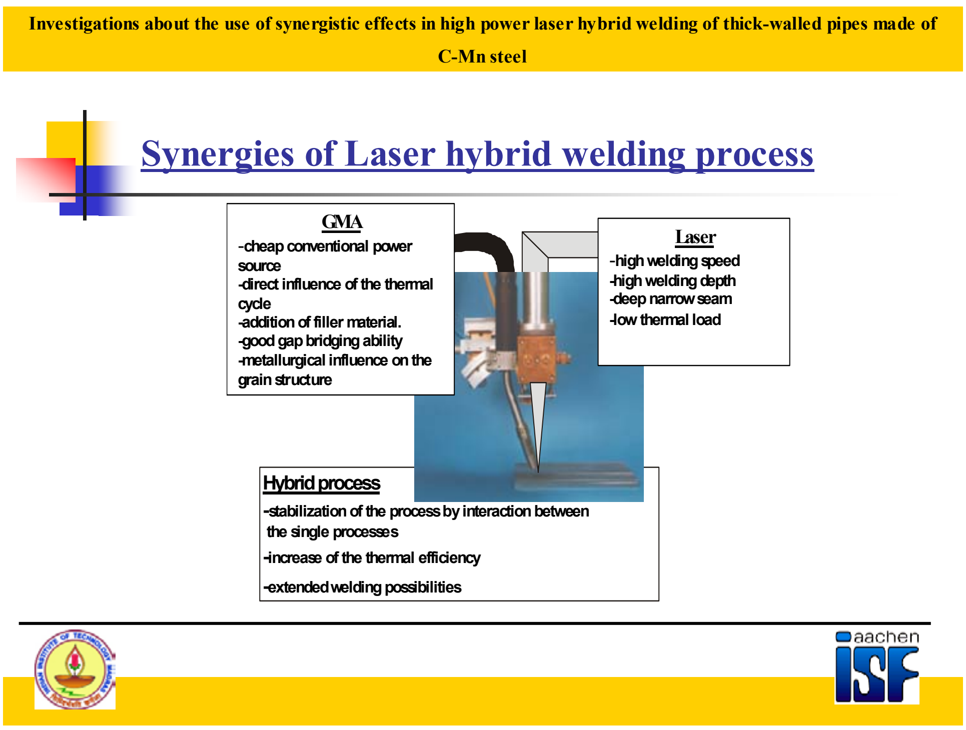

Fig.2. Synergies of Laser-MIG Welding process [5].

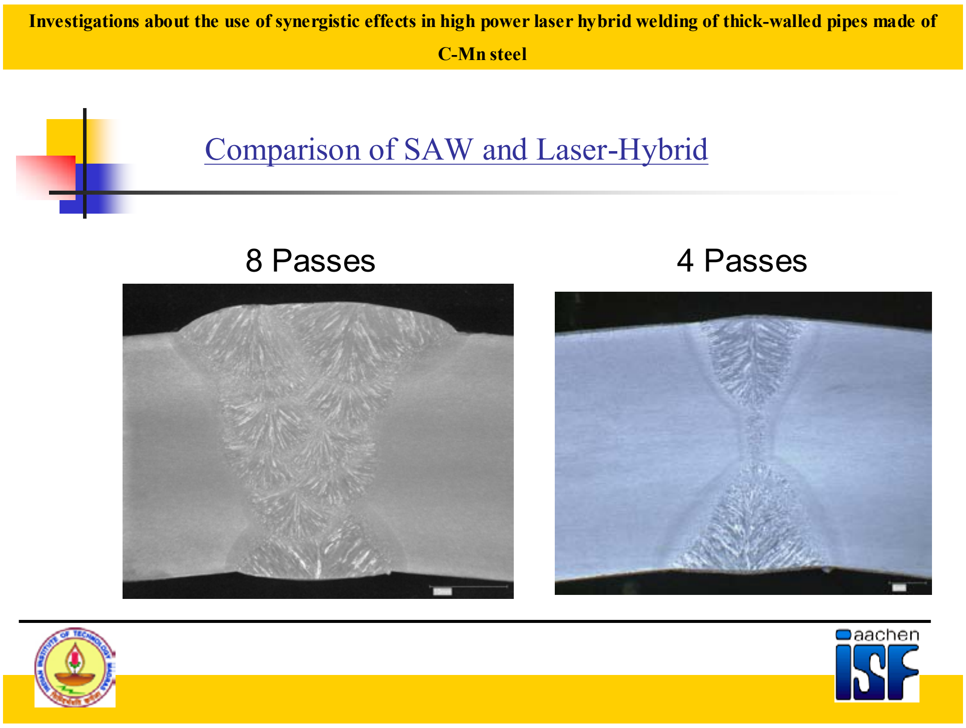

Fig. 3. Comparison of SAW and Laser Hybrid Weld Profiles [4, 5].

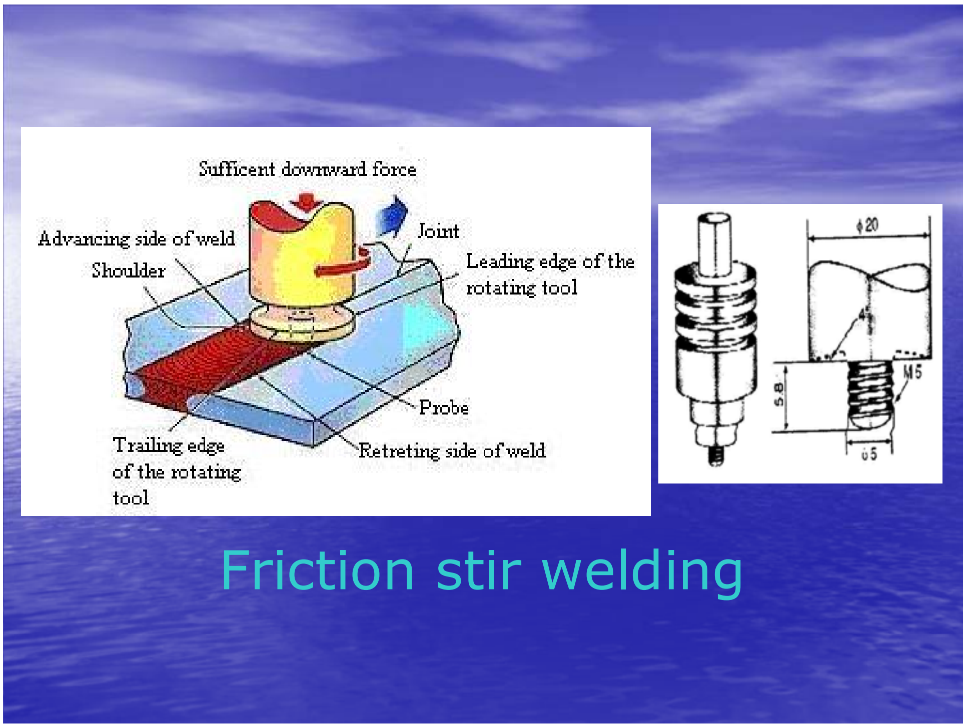

Fig. 4. Schematic Presentation of Friction Stir Welding Process [1].

A Brief Biodata of Prof. D. R. G. Achar

After graduation in Science from the Bangalore University, obtained B.E. degree in Metallurgy from the Indian Institute of Science, Bangalore in 1968. Subsequently, received Master's and Doctoral degrees, with specialization in Welding Technology from the Indian Institute of Technology Madras, in 1971 and 1976, respectively.

Has been a German Academic Exchange Fellow at the Technical University of Braunschweig, Germany during the period 1971-73 and has been re-invited several times by the same Fellowship Foundation during 1979 - 2001. Served as a Guest Scientist on an international research project at the GKSS Research Center, Geesthacht, Germany during 1990-92 and also at the Forschungszentrum Juelich, Germany during 2001- 03.

On invitations has delivered lectures at various Universities / Institutions and Industries in India as well as in Europe, Russia, Ukraine, USA, and Singapore. Has addressed and chaired several technical sessions in national and international welding conferences, including the IIW ANNUAL ASSEMBLY-1984, Boston, USA, the ASIA-PACIFIC CONVENTION ON WELDING & NDT-1987, Singapore and the WELDING-90, Geesthacht, Germany, THERMEC 2000, Los Vegas, USA, 7th Int. Aachener Welding Conference-2001, Aachen, Germany, THERMEC 2003, Madrid, Spain, THERMEC 2003, Vancouver, Canada.

Has been a recipient of several research awards including the prestigious **I.A.E.C. Golden Jubilee Award -** 1984 for outstanding contributions in Welding Technology of Relevance to Indian Industries, **NATIONAL METALLURGIST'S DAY AWARD** of the Ministry of Steel & Mines, India, - 1989 for unique contributions in Welding and NDT technology, **SIR L P MISRA MEMORIAL AWARD** from the Indian Institute of Welding in 1997 and **Prof. DAYA SWARUP MEMORIAL LECTURE AWARD** from the Indian Institute of Metals in 2005. Listed in several International Biographic publications**.**

Has guided a large number of post-graduate students and research scholars towards M. Tech., M.S. and Ph. D. degrees and also sponsored research projects. Has nearly 150 publications in national and international journals, including a Monograph in Aluminium Series published by ALUMINIUM VERLAG, Germany.

Has been a Member of the AMERICAN WELDING SOCIETY, GERMAN WELDING SOCIETY, Life Member of the INDIAN INSTITUTE OF METALS, INDIAN SOCIETY for NON DESTRUCTIVE TESTING, INDIAN SOCIETY for TECHNICAL EDUCATION and a Life Fellow of the INDIAN INSTITUTE of WELDING and a patron of the INDIAN WELDING SOCIETY. Has held several honorary positions like Chairman, Vice Chairman, National Council Member, Patron, etc., of IIW, IWS and IIM. Has organised a large number of courses and seminars on various aspects of welding technology for the human resources development in the industries under the aegis of various professional bodies.

Has nearly 4 decades of teaching, research and industrial consultancy experience in the field of metallurgical & materials engineering, welding technology and allied areas. Served as the Head of the Department of Metallurgical Engineering during 1995-98. Currently, holds the position of **Professor and Head, Materials Joining Section, Department of Metallurgical & Materials Engineering, Indian Institute of Technology Madras**, Chennai, India. Email: achar@iitm.ac.in Web Page: http//www.metallurgy.iitm.ac.in/faculty.