Welding in Heavy Industries –An Indian Perspective

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ABSTRACT

Heavy equipment manufacturers are continuously facing challenges to meet three most important project requirements – Quality, Cost & Delivery. Welding being one of the major operations in heavy engineering industries, welding technologists have to come up with new developments to cope up with these challenges. In order to counter these challenges, significant improvements are taking place in the field of welding and allied areas all over the world. Developments in materials are leading to complementary developments in welding consumable and process technology to weld these materials. Higher productivity processes are being implemented; existing processes are being fine-tuned to make them more efficient. Improvements in quality are being achieved by increased use of automation. Reliability of construction is ensured by the use of advanced NDT techniques. Similar developments are taking place in welding equipments and accessories to improve their efficiency. This paper presents an Indian perspective of developments that have taken place in welding and allied areas in heavy industries

KEYWORDS : Heavy Engineering, Automation, Productivity, Welding, Steels

1.0 INTRODUCTION

Rapid technological developments & economies of scale in process plant industries has led to severe operating temperature and pressure conditions for reactors, pressure vessels and heat exchangers. In the same way, all upcoming plants & equipment for nuclear, defense & aerospace industries are also getting bigger and more complex. To cope up with this trend, new generation materials are being developed worldwide, design aspects are becoming increasingly complex with very stringent quality and safety requirements. In addition, the delivery time is being squeezed to minimize the project cost. All these developments continuously pose new challenges to the welding technologist connected with heavy engineering industries worldwide.

Till the advent of the new century, Indian heavy engineering industries were mainly engaged in catering to the needs of domestic customers for equipment and accessories. In fact, many of the Indian customers were insisting Indian heavy engineering companies to have tie-up with international companies as a pre-requisite for qualification as a bidder. Similarly international customers were not comfortable with Indian suppliers as far as supply of critical equipment was concerned. Some of the Indian heavy engineering industries took this up as a challenge to demonstrate that they were as good if not better than foreign fabricators [1] [2] .

2.0 DEVELOPMENTS IN MATERIALS AND WELDABILITY

There is continuous development in materials for all the industries to improve process efficiency, reduce weight of equipment, improve plant life and reduce plant maintenance / shut down. Designers are coming up with newer variety of materials thereby posing challenges in front of manufacturing industry to come up with suitable technology for processing the same. Following are few examples of development in materials for heavy engineering applications.

2.1 Creep Resistant Cr-Mo Materials

Conventionally, creep resistant 2.25Cr-1Mo material is very widely used in Refinery & Fertilizer applications up to 450°C. Increase in temperature & pressure conditions & also susceptibility to hydrogen attack in such environment called for improved materials. Thus in the late 90's steel makers came out with newer variety of 2.25Cr-1Mo material, known as Vanadium modified 2.25Cr-1Mo material. Use of these high strength materials helps in substantial reduction in vessel weight due to thickness reduction. Typically, changing the material from conventional 2.25Cr-1Mo steel to 2.25Cr-1Mo-0.25V steel will result in to nearly 30% reduction in weight in a typical 1000MT reactor. This is a huge saving and as a result all designers are changing over to this new generation material to take advantage of this benefit [1].

In the past power plant components were also constructed from basic Cr-Mo steel; however increasing conditions of pressure and temperature lead to development of materials with enhanced creep strength. The basic alloy composition was 9Cr -1Mo (P9), which was modified to give the popular P91 (9Cr-1Mo-0.25V) steels. With the advent of supercritical technology, requirements for further enhancement in creep strength has resulted in the W-added category of modified P9 steels called P92.

2.2 Materials for Low Temperature Applications

Ferritic cryogenic steels are nickel containing low alloy steels designed to operate safely at temperatures substantially below 0°C and are characterized by good tensile properties and high impact strength at low temperatures. The nickel content ranges from around 1.5 to 9%. These grades of steel are generally used for the handling and storage of liquefied petroleum gases (LPG) at temperatures down to approximately -100°C and, in the case of the 9% nickel steel, down to -196°C. Competing with these steels are austenitic stainless steels of type AISI 304/304L and AISI 316/316Lwhich are also used for LPG storage at -196°C. Great care needs to be taken in consumable selection and heat input control while welding these steels.

2.3 Special Stainless Steel for Urea application

For fertilizer applications with urea service, the inside surface exposed to the service fluid undergoes very severe corrosive environment. Special Urea grade Stainless Steel (mainly SS316L or 25.22.2LMn i.e. 25%Cr, 22%Ni & 2%Mo) with 'zero Ferrite' is used for such application. However, due to absence of "delta ferrite", there are chances of hot cracking and these steels are difficult to weld. Special weld consumables are used with higher amount of 'Mn' content than that allowed in ASME Sec IIC to take care of 'S' and thereby reducing hot cracking tendency. Welding procedures are required to be qualified with stringent corrosion tests. Rigorous control is required on weld parameters to achieve satisfactory results.

As per some of the process licensors, custom designed Super Duplex Stainless Steel material (e.g. SAFUREX) or Duplex SS (DP-12) are used for such application instead of Austenitic Stainless Steel. These steels also show excellent corrosion resistance and provide an additional advantage on reducing liner thickness due to its higher strength as compared to Austenitic Stainless Steel options. Stringent welding procedure qualification tests including corrosion test and phase balancing (Ferrite-Austenite) are required by the licensors to qualify a fabricator. Indian fabricators have successfully proved their welding expertise by getting themselves qualified to handle these critical materials. Inner Bore Welding (IBW) of this material for Tube to Tubesheet joints poses additional challenge since proper phase balancing (Ferrite & Austenite) is required to be achieved in this autogenously welded joint as addition of filler wire is not allowed. Apart from controlling weld parameters and heat input, selection of suitable gas is also required to meet all desired microstructural, chemical and mechanical properties.

2.4 Ni Alloys & Exotic Materials

The corrosion resistance of nickel makes it particularly useful material. Inconel alloy 690 is a high-chromium nickel alloy having very low corrosion rates in many corrosive aqueous media and high-temperature atmospheres. In various types of high-temperature water, alloy 690 also displays low corrosion rates and excellent resistance to stress-corrosion cracking-desirable attributes for nuclear steam-generator tubing. In addition, the alloy's resistance to sulfur containing gases makes it a useful material for such applications as coal gasification units, burners and ducts for processing sulfuric acid, furnaces for petrochemical processing, and recuperators and incinerators. Inconel 601, 693 & 602CA are used in the fertilizer industry to prevent metal dusting.

Various exotic materials like Ti alloys (Ti-Al-V, Ti-Al-Zr), Zr alloys, Ni alloys (Incoloy 625, 800, Hastelloy C-276, C-22 etc, Co based alloys (Stellite Gr-6 & 1 etc) & Maraging steels (MDN-250) etc are extensively used in both Process plants as well as Nuclear, Marine & Aerospace applications. These materials demand very high level of cleanliness during fabrication and welding (Dust Free Enclosures are required).

Only a handful number of fabricators worldwide including a few Indian companies have been able to develop capabilities to handle the above discussed materials; since they demand high levels of discipline and technical control.

Indian material manufacturing & processing industry is limited to lower end materials like structural steels, boiler grade pressure vessel steel, common stainless steel and few standard Ni alloys. Most of the high end and critical materials are still required to be imported from places like Europe, Japan, and Korea etc. It is not the case that the capabilities to manufacture high end materials do not exist; but it is confined to manufacturing strategically important materials driven by government policy.

Large numbers of manufacturers are available for welding consumables of conventional materials such as carbon steel, selective low alloy steels and most of the stainless steel grades. However, for welding consumables of materials with critical requirements, Indian fabricators are mostly dependent on foreign suppliers.

Even though we are lagging in the manufacture of critical materials and consumables; Indian fabricators have the necessary capabilities to process them.

3.0 DEVELOPMENTS IN WELDING TECHNOLOGY & AUTOMATION

Welding is one of the important operations in fabrication. Recent developments in design & operation have put lot of challenges in front of welding engineers which has led to many innovations such as introduction of new processes/variants of processes, new techniques, mechanization and several others.

Quality and on-time delivery of equipment are the two most important requirements in today's globalized world. Therefore, fabricators are working towards more and more mechanization of welding operations. Some examples of mechanization of welding carried out by Indian heavy engineering industries are described below:

3.1 Narrow Gap SAW

Most of the reactors and vessels manufactured nowadays are of heavy wall thickness (>100mm). While welding of high thickness welds in such equipments, adoption of Narrow Gap SAW technique provides great advantages in terms of reduction in welding consumables and cycle time. In NG SAW, the side walls are nearly vertical (with 0.5° angle) and top opening of the groove is as low as only 28~30mm irrespective of thickness. It is very important to get the welding operation 'first time right' since it is extremely difficult to carry out post weld repairs. Use of contact or non-contact type seam tracking devices and turning rollers with drift control is mandatory for successful welding of such joints. This technique has been successfully applied in welding high thickness Carbon, Cr-Mo and Stainless Steels. Narrow Gap Tandem SAWis one of the process variations of SAW, wherein two (or more) wires are fed from separate welding heads and power sources into the same weld puddle. Use of two wire Tandem SAW increases the productivity by about 90% and is regularly used by fabricators. Capability to weld up to 800 mm thick joints have been demonstrated by Indian fabricators (**Fig. 1**) [5] .

3.2 Weld Overlay by ESW/SAW

For equipments operating with fluid which is corrosive, normally, inside surface of C-Mn or Low alloy steel is cladded / weld overlaid with corrosion resistant material. A typical reactor requires nearly 25MT of weld overlay (assuming 4.5mm thick weld overlay) to cover the entire inside surface of shell courses and heads. This requires development of high deposition welding techniques like Electro Slag Welding (ESW)

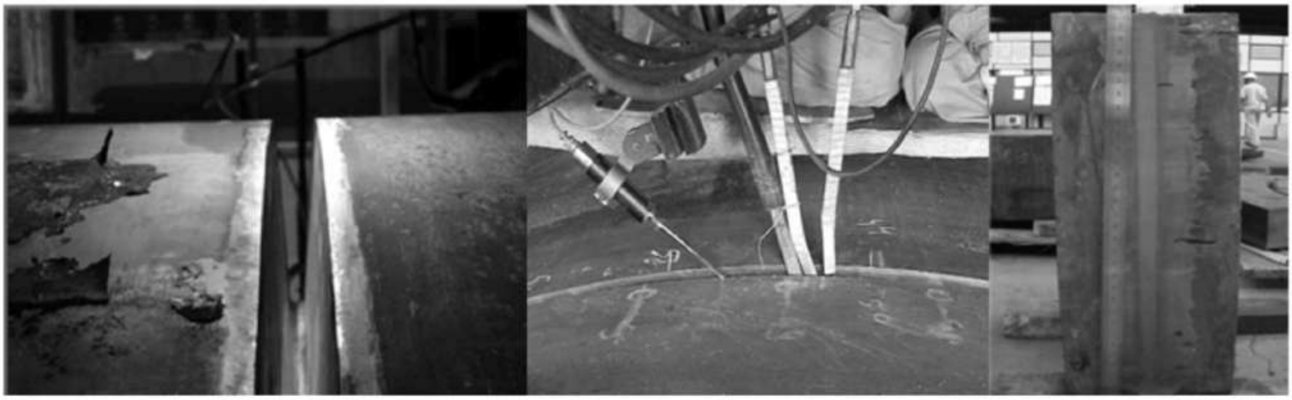

Figure 1 : Narrow Gap Tandem Submerged Arc Welding

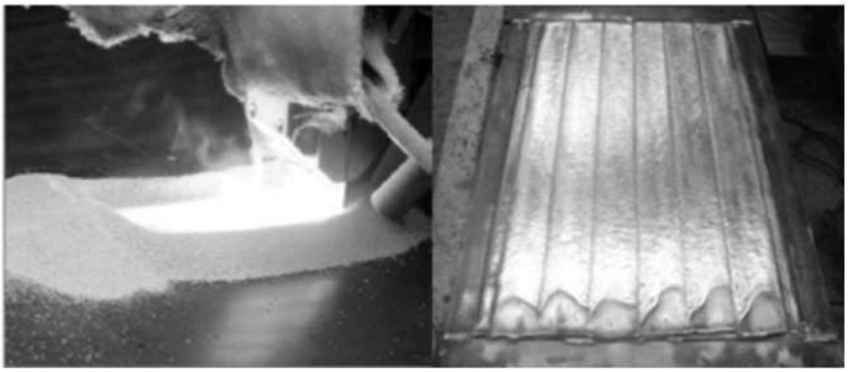

Figure 2 : Electroslag Weld Overlay

(**Fig. 2**) or Submerged Arc Welding (SAW) using strip electrode. Welding is carried out by using strips of up to 120mm wide and 0.5mm thick, which results in deposition of 42Kg / arc-hr. ESW overlay of stainless steels and nickel alloys are regularly carried out by Indian fabricators [6] [7].

3.3 Weld Overlay of Nozzle Pipe / Fittings by Mechanized Processes

All nozzle attachments in a clad / overlayed reactor call for weld overlay on the inside surface as well as on the faces. Special welding torches to carry out weld overlay by mechanized FCAW (**Fig.3**), GTAW or Thin-wire SAW (1.2mm/ 1.6mm dia.) inside nozzle pipes, forgings and 90° elbows. Weld overlay has been carried out successfully on nozzles with very small bore (as low as 25mm) and extra length (as high as 4000mm) (**Fig. 4**) [8]. Wear resistant overlay operations have also been carried out on OD of bars by Plasma Transferred Arc Welding (PTAW) process.

3.4 Nozzle Welding by SAW

All vessels contain several nozzle attachments to its shell courses and heads. All these joints were manually welded till a few years back. As a result, they were highly time-consuming and defect-prone. Mechanized SAW nozzle welding machines have been developed indigenously to carry out Nozzle to Shell / Head Welding in thick vessels. This helps in achieving higher productivity and consistent quality as compared to manual welding. The technique has been further improved by developing SAW for nozzle welding with narrow gap weld edge preparation (**Fig. 5**).

Figure 3 : FCAW on 90° Elbow ID

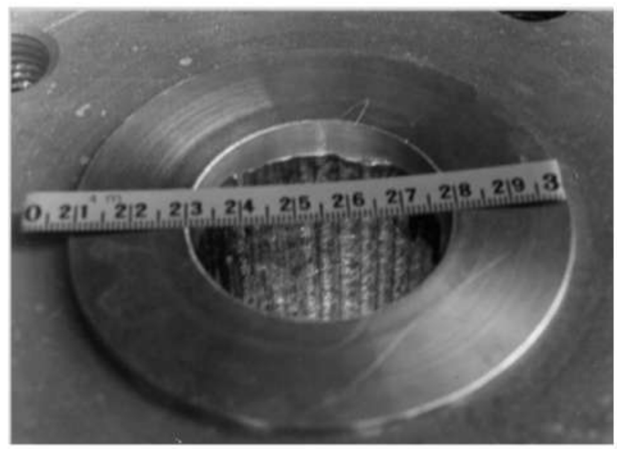

Figure 4 : FCAW on Pipe ID

Fig. 5 : Nozzle to Shell Welding by Narrow GapSAW

3.5 Tube to Tubesheet Welding

All Heat Exchangers and Tubular reactors require a large number of Tube to Tubesheet welds involving wide range of materials like C-Mn steel, Cr-Mo / Cr-Mo-V steel, Austenitic Stainless Steel, Duplex & Super Duplex Stainless Steel, Ni based alloys, Ti &Ti alloys, Zr etc. These joints range from simple heat exchanger & boiler fillet joints to complex Internal Bore Welding (IBW) joints of nuclearsteam generator. These joints are "strength welded" mostly by GTAW process and require very high level of quality and consistency.

Automatic welding of these joints is being done by many of the Indian heavy engineering companies using special purpose Tube to Tubesheet welding machines. These machines produce consistently good quality welds at a fast pace. Over the past decade the percentage of tube to tubesheet joints welded by automatic welding has gone from 5% to 50% of the total tube to tubesheet joints welded.

Due to severe service requirements, many process designers insist on avoiding crevice corrosion for Tube to Tubesheet joints. In such cases, instead of going for conventional Tube to Tubesheet joint design, the design requires Internal Bore Welding (IBW) where tubes are welded to the machined spigots of tubesheet through butt welds (**Fig. 6**). Welding of these joints is done from the ID of the tubesheet hole and necessarily by automatic GTAW process. Weld heads have been developed indigenously by fabricators to weld such joints with or without addition of filler wire. Successful welding techniques have been developed and implemented by Indian heavy engineering industries to weld tubes of ID as low as 31mm with addition of filler wire [9] [10].

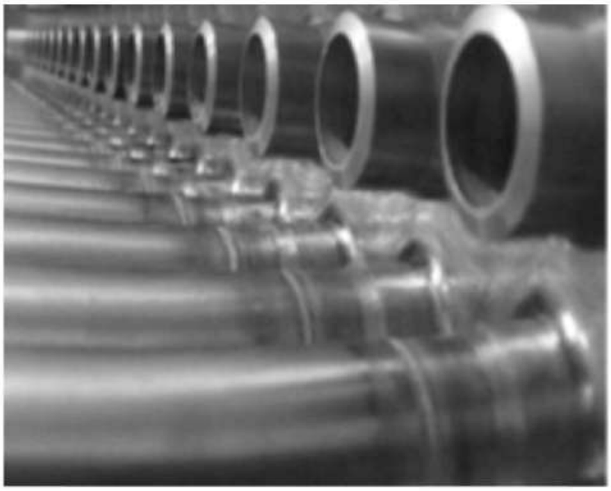

Fig. 6 : Welded IBW Joint and Spigot

3.6 Robotic Welding in Heavy Industry

The use of industrial robots for welding has hitherto been confined to mostly mass production e.g. automobile sector. However, robotic welding can be applied in ship building and pressure vessel manufacture as well. Apart from panel welding applications at shipyard, robotic welding has been used for overlaying critical components of pressure vessels. Examples include weld overlay in bores and profile welding to facilitate clad restoration of the dish end longitudinal seams (**Fig. 7**). Robot welding is also being explored for welding Tube to Tubesheet joints of heat exchangers and boilers. The use of robots enhances productivity as well as set benchmark quality for weld overlay [11].

Fig. 7 : Robotic Welding

3.7 Special Welding Processes

Hot Wire GTAW, a variant of GTAW process is finding its applications in Narrow Gap butt welds as well as weld overlay (Stainless & Ni alloys on Ferritic steel). Procedures have been successfully developed for welding of highly critical 9Cr-1Mo

Fig. 8 : Setup for Carrying Out Hot wire GTAW

steel in Fast Breeder reactor components. Developments are in progress to use Hot Wire GTAW for welding of 500mm thick Tube sheet Longitudinal seams and also for closing circular seams of Super Heavy Tubular reactors where avoiding rotation of job will result in significant saving in cycle time.

Metal Cored Arc Welding process uses a hollow metal tube filled with a blend of metal, mineral, and chemical powders, known as metal cored wire. The majority of the core is iron, and additional elements are added to produce specific results based on the materials and applications. The wire is generally used with 100 percent CO_2 or an argon/CO_2 mixture, with the richer argon mixtures being the most common. This process combines the best properties of a solid wire and a flux cored wire. High deposition rates and efficiency, minimal slag & low spatter are the advantages of this process (**Fig.10**).This process has been successfully used to weld many Cr-Mo boiler membrane walls (**Fig. 11**) and has virtually replaced the earlier GTAW+SMAW route.

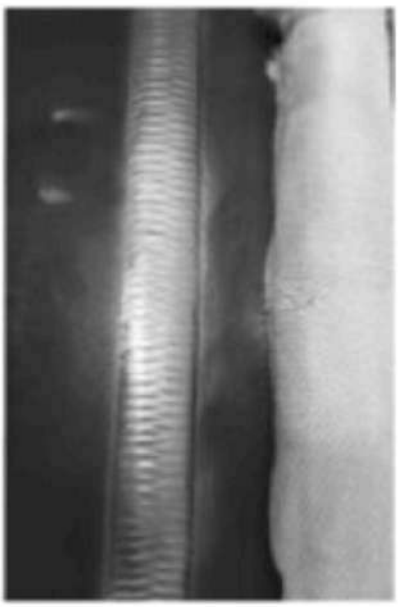

Fig. 8 : Visual of Circumferential Seam Welded by Hot Wire GTAW technique

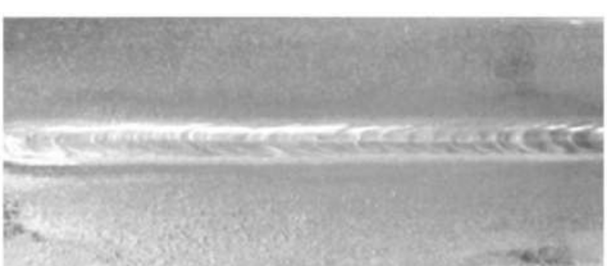

Fig. 10 : Bead Finish of Metal Cored Arc Weld

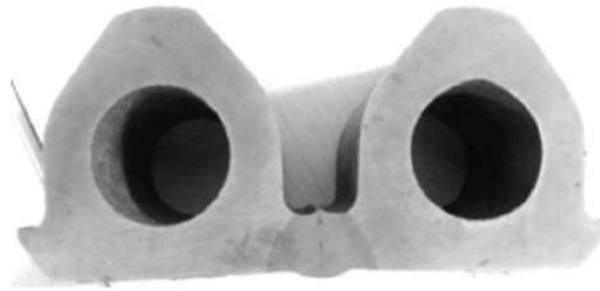

Fig. 11 : Boiler Tube Welded with Metal Cored Arc Welding

There are many capable system integrators who can supply welding automation systems. They generally import the system components (power source, heads etc.) and carry out integration. Large fabricators have in-house departments to take care of automation needs, however they also rely on imports for system components.

4.0 DEVELOPMENTS IN HEAT TREATMENT

Most of the reactors / vessels/ heat exchangers being manufactured using C-Mn steel or Low Alloy Steel (LAS), call for post weld heat treatment (PWHT) after welding. PWHT is required to be done under controlled soaking temperature and time range to ensure the desired properties of base material, weld metal and heat affected zone. Heat treatment are carried out in specially constructed furnaces. Some of these furnaces use special controllers to automatically control heat input so that uniform temperature is maintained (**Fig.12**). Standard heat treatment technology exists with most of the fabricators. Specialized vendors are also present who can build furnaces and carry out heat treatment for customers.

Fig. 12 : Fully Automated Furnace for Post Weld Heat Treatment

5.0 DEVELOPMENTS IN QUALITY CONTROL & ASSURANCE OF WELDED CONSTRUCTION

Each weld joint of a vessel calls for stringent inspection and testing requirement as per the requirement of manufacturing code, customer specifications and other applicable standards. The tests generally include Non Destructive Tests (NDT) like Radiography (RT), Ultrasonic Test (UT), Magnetic Particle test (MPT) & Dye Penetrant Test (DP) in addition to thorough visual examination. Out of these tests, RT & UT are given maximum importance. Due to the higher wall thickness of the vessels, RT is being preferably done using a high power Linear Accelerator (LINAC). On the other hand, Micro focal anode X-ray is being used for detection of flaw in Tube to Tubesheet joints for critical nuclear application.

The concept in NDT has shifted from 'only flaw detection' to 'flaw detection, characterization and flaw sizing'. There is huge advancement in UT technology over the last few years. High resolution UT including Time of Flight Diffraction (TOFD) has become a mandatory requirement for all critical reactor weld joints. Phased Array UT is also being considered very seriously by many process licensors for application on critical equipments. Automatic UT of Tube to Tubesheet joints for various nuclear applications (e.g. Bi-junction welds in End Shield) and similar other critical applications have been developed using immersion UT technique. Stringent requirements of nuclear and aerospace projects have taken the capabilities in carrying out various NDT to its zenith.

Welding documentation has moved from paper to paperless through application of information technology. Software's exist in market for taking care of all welding and quality related documentation. Large fabricators have utilized their in-house expertise to develop "Quality Document Management Systems' to suit their requirements. Using such systems has resulted in correct information being available to proper personnel at right time. Another advantage is that the data generated can be analyzed to better enhance productivity and quality. Information systems are also utilized for welding consumable issue, which is linked to a welder's smart card. This prevents wrong consumables from being issued and proper accounting of consumable utilization takes place.

During manufacture, apart from computer control of the various parameters use of data loggers is common place for many applications. The data loggers can serve either as quality surveillance or productivity management tool.

6.0 WELDING HUMAN RESOURCE DEVELOPMENT

Most welders are trained in Industrial Training Institute's (ITI's) and other vocational training institutes. These institutes do not provide them sufficient grounding. Thus when they join the industry as apprentice, they face an altogether different scenario. Having been trained in older generation machines, they are forced to unlearn and begin afresh. This is one of the causes for the present crisis we are facing of paucity of good welders. To address this issue many large fabricators have in-house training programs where they groom prospective welders with basic and advanced training.

Virtual welding simulators are available for GMAW & SMAW welding training. Apart from savings in materials and consumable cost, another advantage with these simulators is that the entire movement of welder can be captured by the trainer and later on shown to the welder. Such training simulators ensure consistency, speed & quality in the training. This also reduces requirement of experienced trainers, who anyway have become a rare commodity.

Most welding engineers are either mechanical or metallurgy graduates. In India, till date, very few institutions are providing advanced studies in welding technology. Few of them are IIT-Madras, IIT-Roorkee, and NIT-Trichy for post-graduates and SLIET-Punjab offers both under graduate and post graduate programs. IIW has also started some of the programs which give education in welding like AMIIW course or some diploma courses through collaboration with International Institute of Welding. The ME-Welding Technology program offered by M S University, Vadodara is a unique industry-academia collaborative program in which equal emphasis is placed on academic and industrial training.

7.0 CONCLUSION

Significant changes have taken place over the years in welding and allied areas in heavy industries in India. From making simple equipments with basic materials to fabricating the most complex ones involving stringent quality requirements, the Indian heavy engineering industry has evolved a lot. The industry has become mature and can compete globally for various orders, due to its demonstrated capabilities in welding and allied fields.

REFERENCES

[1] P. Chattopadhyay, "Indian heavy engineering industry - creating global benchmarks," in Global Trends in Joining, Cutting and Surfacing Technology, 2011, pp. 449-456.

[2] Y. S. Trivedi, "Heavy Engineering Manufacturing Technology in India - A Current Perspective," in IWS 2K12 International Welding Symposium, 2012.

[3] J. K. Nanda, D. V. Kulkarni, and A. K. Ramakrishna, "Advances in SAW and Narrow Gap Welding," in Annual Welding Seminar, 1994, p. Mumbai.

[4] P. Chattopadhyay and Y. S. Trivedi, "Welding of heavy engineering components in India," in Joining the World. Commemorative Monograph, Welding Science and Technology Competence in India, 2008, pp. 1-10.

[5] H. Desai, A. Mistry, M. Ghosh, and G. Iyer, "Narrow groove welding procedure development for 800 mm thick plate," in Global Trends in Joining, Cutting and Surfacing Technology, 2011, pp. 107-110.

[6] P. Chattopadhyay, M. K. Mukherjee, and Y. S. Trivedi, "Development of manufacturing technology for fabrication of high pressure reactors, converters and tubular reactors through plate route at Larsen and Toubro Ltd - India," in European Symposium on Pressure Equipment, 2007, pp. 450-455.

[7] T. Hansen, M. K. Mukherjee, D. V. Kulkarni, and C. Y. Deshpande, "Double Strip Cladding," in National Welding Seminar, 1992.

[8] P. Chattopadhyay and Y. S. Trivedi, "Developing manufacturing technology to overcome new challenges in heavy engineering applications," in DVS Berichte, No.237. Welding and Cutting, 2005, pp. 525-529.

[9] D. S. Bajpeyee, P. B. Patil, and D. V Kulkarni, "Development of tube to tubesheet welding of steam generator for Prototype Fast Breeder Reactor," in International Conference on Advances in Manufacturing Technologies, 2008.

[10] D. S. Bajpeyee and D. V. Kulkarni, "Experience of development of automatic welding for critical tube to tubesheet joints," in National Welding Seminar, 2009.

[11] K. Iyer, A. Singh, R. Gupta, and M. K. Mukherjee, "Robot Welding in Pressure Vessel Equipment Manufacture," in Annual Welding Seminar, 2010.

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Mr. Karthik Iyer graduated as a Metallurgical Engineer in the year 2008 and joined the Heavy Engineering Division of L&T. He was initially responsible for welding planning & shop floor monitoring of Coal Gasification equipments. He pioneered the introduction of robot welding in pressure vessel component manufacture. He also established the welding development centre at L&T, Powai. He has taken a number of knowledge management initiatives. He is an 'Advisor' of AWS Technical Committee C5 on Arc Welding and Cutting & D16 on Robotics and Automatic Welding. He is also an Associate Member of the Indian Institute of Welding. He passionately pursues welding automation. He is currently pursuing a company sponsored part time M.Tech course at Indian Institute of Technology, Bombay (IIT-B).