Transforming India – Few Significant Developments and Prospects in Welding Technology

Mahadev Shome
Head, Materials Characterization & Joining, R&D, Tata Steel, Jamshedpur, India

DOI : 10.22486/iwj/2018/v51/i2/170311

1.0 PREAMBLE

I feel humbled in being considered to deliver the revered Keith Hartley Memorial lecture of the Indian Institute of Welding, and am really grateful to the Jamshedpur Branch for nominating me and the jury who found me deserving. Given this opportunity, it's an honor to share with you some of my work and contributions made in the field of 'welding and joining' engineering. I would also like to take this opportunity to salute late Mr. Keith Hartley, who laid the foundation of the Indian Institute of Welding with a vision to make quantum progress through cooperative efforts of professionals, and the success story of the manufacturing industry in the country in the last 20 years stands testimony to a mission partly accomplished and progressing rapidly to attain new heights.

Since the dawn of this century, electronic gadgets like mobile and smart phones, laptops and tabs, digital technology and cloud computing have hogged the limelight as far as game changing technology is concerned. Truly the transformation has been mind boggling even in a country like India and has impacted society at large; unthinkable two decades back. Consequently the attention on core engineering has been sidelined despite making major strides resulting in significant industrial growth over the last two decades. As far as welding technology is concerned, the major thrust has been in construction, fabrication and component manufacturing involving the established arc welding processes like SMAW, GMAW and SAW. The arc welding processes have advanced through improved machines technology with intelligent control features, joint design and weldability of new materials. Programmable weld machines eliminate the cost, human error and effort spent in guiding welders all the time. Narrow gap welding and automatic welding are boosting the efficiency of arc welding and making manufacturing more productive. Other welding processes, like resistance spot and seam welding (RSW), flash butt welding(FBW) and high frequency induction welding (HFIW) have gained greater prominence because of greater demand for engineering and automotive parts. Several hi-tech processes like laser, laser hybrid welding, friction-stir welding and magnetic pulse welding are been strongly pursued for commercial applications in a country where the per capita GDP remains to be low but gradually increasing. In this lecture I will take you through a couple of my involvements in the last two decades that has made significant business impact through R&D efforts.

2.0 DEVELOPMENT OF DIRECT DRAW QUALITY WIRE RODS FOR GMAW (2000-2002)

Beginning in the 70's, the GMAW semi-automatic process had made a strong footing in India by 2000. Initially the MIG wires were produced with random winding, but later on spools with regular winding became available mostly with wire size of 1.2 mm diameter complying with AWS E70S-6 standard. It had become an acceptable product for structural fabrication and heavy engineering welding and was growing at an enormous rate. At that time, the wires were produced by reputed electrode manufacturers by a series of processes, viz. mechanical descaling and primary drawing operation followed by intermediate annealing (**Fig. 1**). Post annealing the intermediate wire was finish drawn to the final size of 1.2mm/0.8mm, coated with copper by either dipping in a bath containing copper sulphate solution or by electrolytic means. The intermediate annealing was aimed at softening the hard matrix, followed by pickling to remove the newly formed scale at the time of heat treatment.

Prominent international manufacturers had by that time had developed direct drawing from 5mm/5.5mm wire rodsto 1.2mm/0.8mm wires through two stages; primary drawing followed by high speed (>50m/s) secondary drawing. There was no intermediate annealing process. This was a simpler and cheaper process on account of lower electrical power consumption, reduced overhead cost, less maintenance effort, lesser floor space area, more yield and higher productivity. It also caused less environmental damage due to elimination of acid pickling. As such the manufacturers of wire consumables were going difficult times because of sluggish market and stiff price competition. Therefore there was this intense drive to eliminate the intermediate processes and make the product profitable and adhere to pollution control norms. However, the basic information to implement direct drawing was not known even by the big brands despite having international tie ups. It transpired that the AWS prescribed steel composition was broad based aimed at achieving welding properties, and did not provide any clue about producing wires from wire rods by direct drawing. Given the distraught situation, the welding consumable manufacturers approached Tata Steel for developing 5.5 mm wire rods with direct draw features.

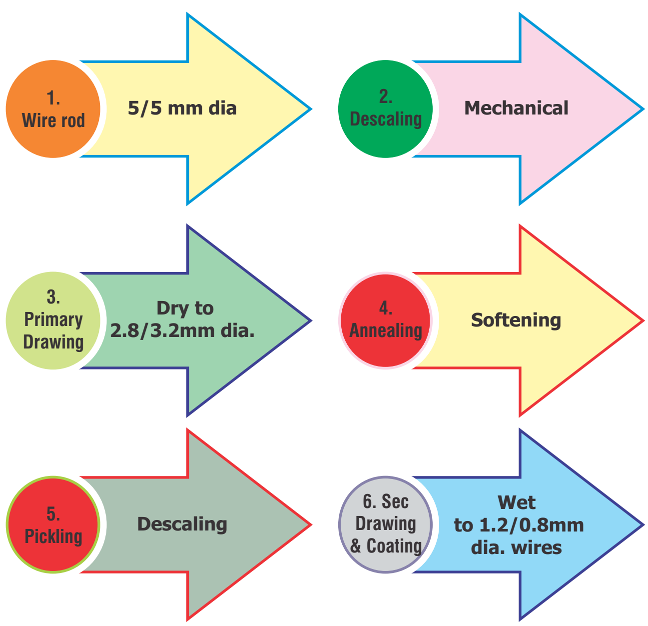

Fig. 1 : Process steps for manufacturing GMAW wire of ER70S-6. Steps 4 and 5 have been eliminated after introduction of direct draw quality wire rods

Even after carrying out extensive literature survey, studying reports, and having long interaction with the electrode manufacturers, no significant insight was obtained regarding the key factors that control drawability. The search for information was on and became quite a challenge as the market expected a quick product. A major project was taken up in the R&D of Tata Steel to develop this wire. Available local sources as well as international wire rods from different manufacturers were investigated for steel chemistry, mechanical and other physical properties and verified with AWS ER70S-6 specification. All wire rods adhered to the chemical specification and therefore the mystery remained folded. Subsequently while analyzing the drawing process and the high strength values of the drawn wire at the intermediate stage of 3.2 – 3.6 mm, it appeared that dynamic strain ageing took place in the steel during primary drawing operation **(Fig. 2)**. This discovery threw some light on the drawability issue.

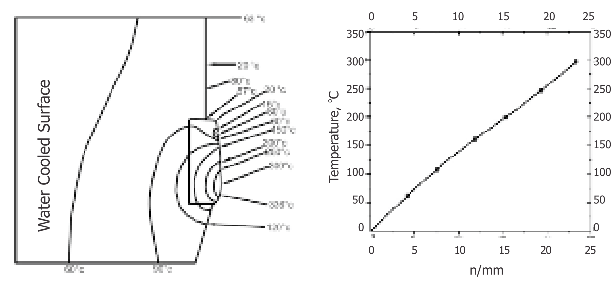

Fig. 2 : Temperature rise in die and wire rods during drawing operation

During drawing operation, the interaction between the steel rod and die causes deformation induced straining in the wire rod along with increase in temperature. The strained matrix at elevated temperature experiences dynamic ageing when the interstitial content in the steel is high. All this analysis hinted towards nitrogen as the most likely element to cause strain ageing, and experimental findings concluded that steels with high nitrogen (>70ppm)had issues with direct drawing. This also indicated that the chemistry for direct draw quality wire rod was a small subset of the AWS specification. Another important factor was the volume fraction of pearlite in the steel; anything above 15% was undesirable. This again was linked with the carbon content in the steel and the hot rolling parameters in the wire rod mill. As part of the development effort, LD furnace steel making process was established to restrict nitrogen in the steel. Steel with less nitrogen content showed lower strain ageing index **(Fig. 3)**. Extensive thermo-mechanical simulation studies **(Fig. 4)** helped in optimizing the rolling parameters for achieving appropriate pearlite volume fraction of less than 10% **(Fig. 5)**. The direct draw quality CO_2 welding wire rod development was a big success benefiting the entire welding industry and generated a business of about 6000t/year for Tata Steel in year 2001. Today this business has grown to 1,00,000t/year and is one of the most sought after long products.

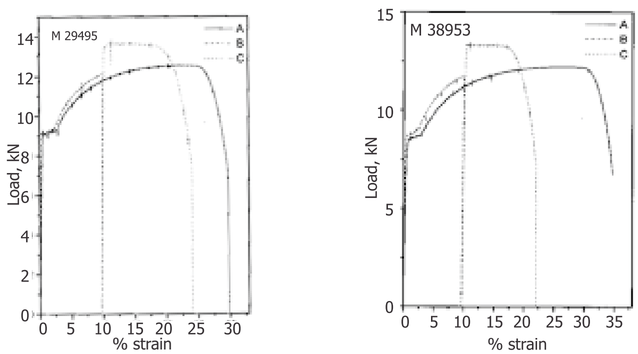

Fig. 3 : Strain ageing tests on (a) 53ppm N; (b) 74ppm N steels; (a) SAI=10.01; (b) SAI=13.98

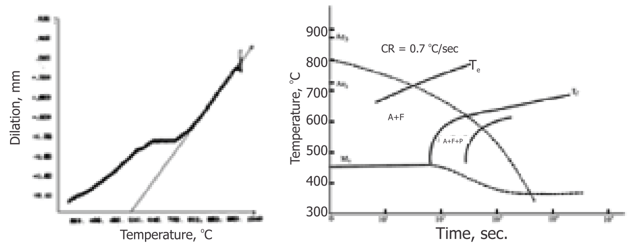

Fig. 4 : Thermal simulation (dilatometry) to obtain CCT diagram for hot rolling of wire rods

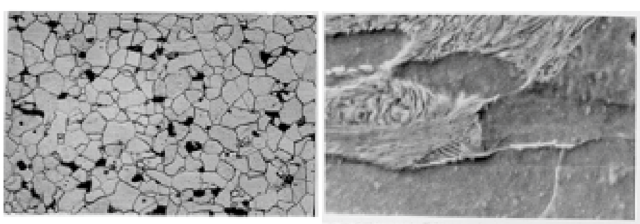

Fig. 5 : Microstructure in wire rod: 90% ferrite; 10% resolved pearlite; 10-12μm grain size

3.0 RESISTANCE SPOT WELDING OF COLD ROLLED STEEL – LEVERAGING THE AUTOMOTIVE BOOM (2004 – 2017)

Cold rolled steel sheets for automobile application was launched in India at the turn of the century. This was driven by the entry of a large number of foreign automobile companies primarily through joint ventures. These steels were in the class of 300-440MPa ultimate strength with good formability. Amongst them interstitial free (IF) steel was introduced in the market for the first time in India, both in bare and coated condition. The major volume was as bare sheets, but for niche applications zinc coated steels was used because of improved corrosion resistance. The coated version was 'galvannealed (GA)' steel, which had layers of Zn-Fe alloys within a coating thickness of ~8μm.This alloy was obtained by annealing soon after hot dip galvanizing. Apart from IF steel, other coated steels were produced with different steel matrix varying from extra deep drawing quality to CMn440 high tensile steels. While all these coated and high strength steels were being developed, a major bottleneck was resistance spot welding as there was limited expertise to deal with application issues. Most auto OEMs were familiar with spot welding of low carbon bare steel, but it was essential to apply different welding parameters on galvannelaed steels to obtain acceptable nugget diameters. The shear and cross tensile properties and fatigue performance largely depends on the nugget size. A big gain was that the mandatory approval tests demanded by the automotive companies compelled us to master the subject. This also helped in product development in the steel plant as well as application in the automotive units.

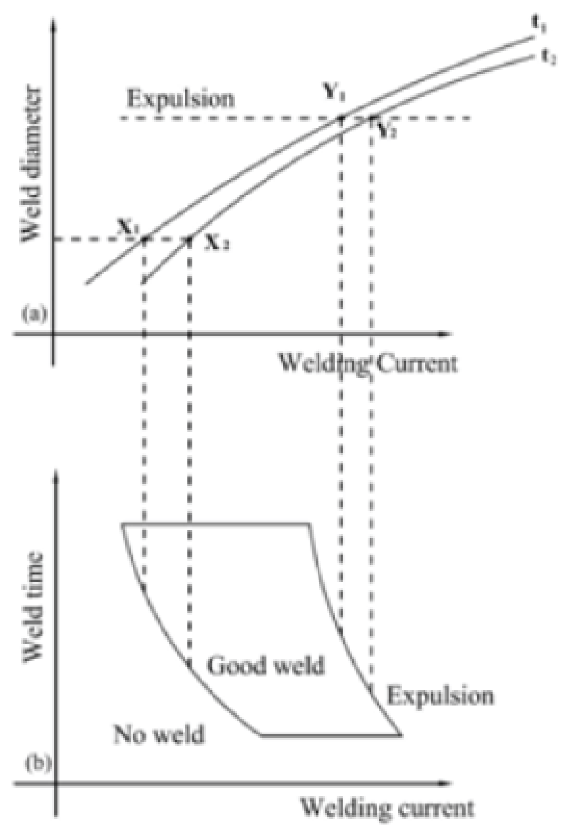

Fig. 6 : Weld lobe and nugget growth curves (Williams & Parker, Int. Matl. Rev., 2004)

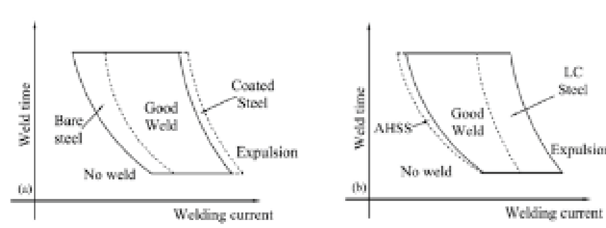

Fig. 7 : Weld lobes for (a) coated steel vs bare steel; (b) AHSS vs LC steel

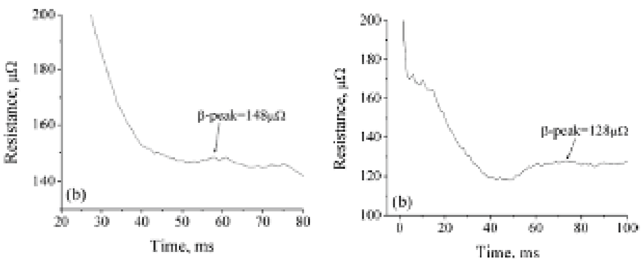

Fig. 8 : Dynamic contact resistance of interfacial (i) bare, (ii) coated steel of 0.8mm thickness; weld time 120ms

Table 1 : Variation in nugget diameter of coated and bare steel of 0.8mm thickness

Steel Grade	Current, kA	Weld time, ms	Electrode force, kN	Heat generated, J	Nugget size, mm
IF (C)		200		1481	5.2
IF (B)	8		2.3	1836	6.2
IF (C)				825	4.0
IF (B)		120		1024	5.1

The information available in the early years was limited to a few literature reports on RSW of low carbon bare and coated steels **(Fig. 6)**. It was apparent from literature that coated steels were relative difficult to weld because of constricted welding lobe **(Fig. 7)**. With that in the background detail investigation was carried out to identify the welding parameters of coated steel vis-à-vis bare steel following a standard process laid down in BIS 1140-1993 and SAE/AWS D8.9M. The results showed that the weld lobe shifts to higher current values in order to maintain the same nugget size, but the lobe width is reduced in coated steels. The expulsion on account of zinc limits the current range on the higher side. It became evident that presence of zinc coating on one hand reduced the static contact resistance, but early vaporization limited the operating range. Compared to bare steel, the overall dynamic contact resistance (DCR) of coated steel is lower and produces smaller nuggets with identical parameters **(Fig. 8, Table 1)**. In addition the zinc coating on the steel interacted with the copper electrodes and formed Cu-Zn alloy on the electrode face, expanding the diameter and thereby reducing the current density. This resulted in smaller nuggets with increasing number of spot welds. Regular dressing of the electrode is necessary till the surface is rendered unusable. The electrode life was found to be lower in case of GA steel. For a 0.8mm thick GA sheet, the electrode life could be anything between 2000 to 2500 spot welds with interim electrode dressing, against >5000 spot welds for bare sheets **(Fig. 9)**.

Fig. 9 : RSW: New and used Cu-Cr-Zrtruncated cone electrode capswith 6mm face diameter (for GA steel)

In recent times the introduction of advanced high strength steels (AHSS) in vehicles produced in India has made the task more challenging for welding engineers. Compared to low carbon steel, the welding current range for AHSS is lower for nugget formation **(Fig. 10)**. The presence of more alloying elements increases the material resistivity and under the influence of temperature the dynamic contact resistance increases quickly resulting in higher heat input. A major issue with AHSS welds is the formation of brittle phases, primarily martensite, under rapid cooling conditions experienced during spot welding. Unlike plug failure in low carbon steels, the acceptance criterion for AHSS steel weld joints is the shear and cross-tensile strength. In most cases AHSS steels with small nuggets (4√t - 5√t; t is thickness of sheet) experiences interfacial failure. Higher currents produce large weld nuggets in AHSS that undergo plug failure during tensile shear testing. It is however not recommended as power consumption is high, causes low expulsion and reduces the electrode life by softening the electrode face. In case of coated AHSS, the weld shift is prominent after 200 spot welds and frequent electrode dressing is necessary for enhancing the life of the electrodes.

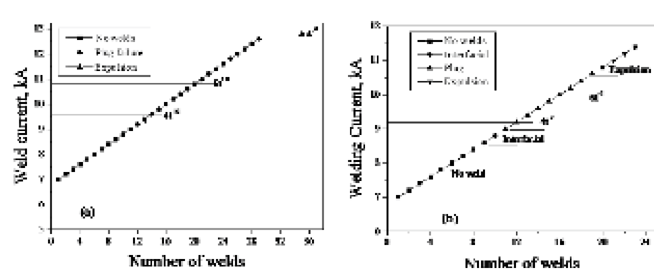

Fig. 10 : Current range for welding coated (a)drawing quality (DQ) and (b) DP780 steel sheets (1.2mm thick)

The RSW data generated on a variety of steels have been shared with the automotive OEMS for product approval purpose. In many cases it has helped them stabilize their process, especially in tire I and tire II auto ancillaries. Currently finite element based software are often used to accurately predict the nugget size, expulsion and metallurgical results once the assembly details and welding conditions are given as input to the model. Several automotive companies accept these results for material approval purpose. Apart from routine tests, the commercial models are able to provide valuable inputs, that aren't available through experiments. Most significant are the distortion effects and temporal conditions which are helpful for studying phase transformations in the weld nugget of special steels and alloys.

4.0 ADVANCED WELDING PROCESSES – JOURNEY INTO THE FUTURE (2016 – 2017)

With increasing focus on high end value added products and reduction of waste as part of the ecosystem, additive manufacturing (AM) has become a hot topic with great potential. This technology has the capability to manufacture complex parts with intricate design. A technology that was introduced for rapid prototyping has progressed over the years and is gradually emerging as a strong alternative route for manufacturing. The capability of directly converting CAD drawing to actual physical part, without any machining operation, reduces cost of expensive tools particularly when only few parts are needed. This technology is also promising in those areas where large inventories are not desirable. In such situations AM can be used to make parts on an on-demand basis thus leading to reduction in both lead time and production cost. AM technologies also have the potential to reduce raw material consumption since they have a much lower buy-to-fly ratio compared to traditional technologies which are associated with a large amount of scrap generation. The above mentioned advantages have made it successful for medical applications, aerospace and niche automotive components. Now the effort is to extend this technology for more common engineering components that are difficult to manufacture by the subtractive process and would be cost competitive. One upcoming AM method is laser metal deposition (LMD), wherein layer upon layer cladding is done to make objects from 3D model data.

The LMD set-up essentially has a laser source, powder feeder and a robot or CNC tool holder to carry out the operation. Once integrated, the software reads the CAD drawing of the component and navigates the motion of the laser head to build the component. As the powder is delivered from the cladding head, the laser melts the fine powder and deposits them on the substrate. As manufacturing solid parts with currently available atomized powders have cost implications, topological optimization helps in reducing the volume and in turn enhances productivity. Currently the available powders are mostly high temperature alloys and are expensive for producing engineering parts. The current efforts are on developing air atomized alloy steel powders within the country suitable for regular applications. In Tata Steel, we have identified several components and exploratory work has started **(Fig. 11)**. A major research objective is obtaining functional properties in the steel deposits, for which extensive cladding and characterization work is in progress. Efforts are on to understand the complex interaction of laser processing parameters and the underlying physical and chemical metallurgical mechanisms responsible for the variation of microstructural and mechanical properties in the products. A three year internal plan is in place to make this initiative a success.

Fig. 11 : Spur gear produced by additive manufacturing after topology optimization

5.0 WELDING LANDSCAPE – PROSPECTS

Welding is a basic technology that has brought in high levels of sophistication in the manufacturing industry. Properties of weld joints essentially determine the performance of a structure. Like other technologies it is evolving rapidly. Research in recent years has enabled in changing the landscape of welding with the development of several new technologies. By 2030 the steel demand projection is 230MT in India as against 82MT now. Bulk of the steel consumption is likely to be in the five key areas viz. infrastructure, construction, engineering and fabrication, automotive and energy **(Fig. 12)**. Overall economic growth would present a situation with a basketful of attractive steel products for various sectors. This would include thick high-strength steel plates (80-100mm) for construction and ships, eco-friendly steels, high alloy corrosion resistance steel for marine application, fire-resistant steels, earthquake resistant steel and high-tensile steels for the automobiles. Apart from steel, heavy titanium plates would find application in shipbuilding and offshore structures given its excellent corrosion resistance, high strength and low weight.

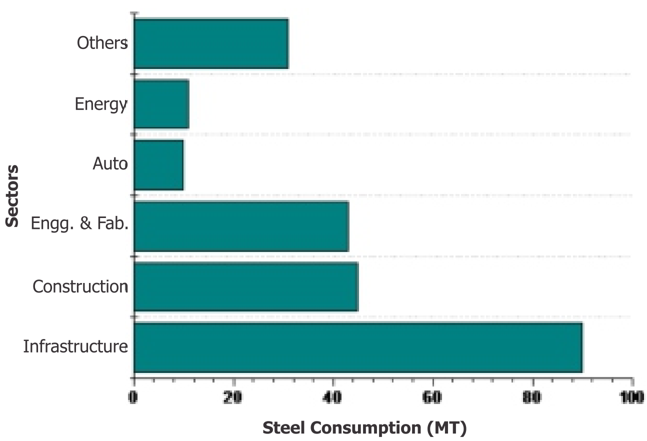

Fig. 12 : Projection of finish steel demand in 2031 (Ref. Ministry of Steel 2017)

With several new generation steels available, there is renewed focus on welding of thick high tensile plates with stringent requirement of weld and heat-affected zone (HAZ) properties. A new way of improving the HAZ toughness is preventing brittle phases by adopting an innovative pass sequences and heat input technique in the final layer of multi-pass welds. The single pass two electrode electrogas arc welding is another novel high heat-input technology that restricts grain coarsening in the weld of heavy gauge plates, especially for ships and high-rise buildings. It scores over the conventional CO2 welding in terms of cost and productivity. Narrow gap welding has evolved to overcome the limitations of both processes. SAW with small diameter wire is now used to comply with such requirements. The high-current, high-speed SAW with multiple electrodes is something of the past.

Intelligent spot welding provides synergic control on welding current and electrode force during welding of automotive parts, moving away from the constant current and force technology. Again the pulse spot welding technology uses a high-voltage, short-duration current to control segregation in the weld joint. This ensures proper cross tensile strength of welded ultra-high strength steel sheets. In the near future, laser welding may replace resistance spot welding in the automobile sector. Automated robotic welding addresses increasing customization, superior quality and shorter delivery schedules and are likely to be increasingly used. Current robots are capable of narrow gap welding of heavy plates and on-site girth welding of gas pipelines.

There are a lot of new technologies on the anvil with exciting prospects of producing world class engineering products. A strong and vibrant manufacturing sector is essential to propel the economy of a developing nation. A radical shift in welding technology is foreseeable and the country is poised to change for the better.