Economics in Welding

A Technological Perspective on Consumables and Equipment

By A. C. LAHIRI*

1.0 Introduction

With the social and economic pressures ever increasing on fabrication industries, the development of high productive welding consumables and equipment is perhaps the most important area where maximum emphasis is needed. Time has now come to reassess the state of technology of these products against the fast changing economic background.

With the state of art prevalent in the international scene it must be accepted that in the immediate future, possibly with the exception of Robotics there are no new welding processes which are going to make any significant impact on fabrication. Therefore the industry must use the existing welding processes better and take advantage of the increased deposition through either process conversion or by the use of many of the variations available for the conventional processes.

To quote Reynolds, 'There are two important factors that contribute directly to final cost of welding,—

Deposition rate, and

Duty cycle

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Between them, these two terms cover almost every significant element or feature which can contribute to welding cost including over welding, welding supervision, weld quality parameters, defects and repairs and welding engineering. The great influence of these items on welding cost can never be over emphasised. Considerable amount of work has been carried out in India on the improvement of welding economics and a large number of practical work, case studies and the derivations out of these have been published in the last decade or so. But for a variety of reasons, welding economics as a whole has not grown to reflect this awareness and we have by and large lagged behind the developed and some developing countries in achieving the targets. One of the causes for this slow growth is often said to be attributable to our apparent reluctance in understanding the implications of the use of some of the welding processes that are dominating the industrial scenes elsewhere and also our inability in producing equipment and consumables which are reliable enough to offer trouble free service over a reasonable period of time to justify the economics. Perhaps it has now become necessary for us to change the emphasis so that the best use of consumables and equipment can be made in the interest of welding economy in our country.

2.0 Manual Metal Arc Welding

The first step towards improving welding productivity with stick electrodes was taken in the year 1932 in

England when iron powder electrodes were used. In India these electrodes were developed in the mid fifties and later two types of electrodes with iron powder (i.e., basic coated and rutile types) have found use in industries. Although almost 70 iron powder electrodes are manufactured under different brand names by various electrode manufacturers, it is observed that out of these about 3 or 4 types can really be used for achieving higher deposition rates at deposition efficiences 120 – 140%. Other uses of iron powder in the coating of electrodes are mostly to ensure better arc stability, accurate running characteristics and faster burn off rates and majority of electrode manufacturers are concentrating on these aspects rather than increasing deposition efficiencies.

The technical disadvantages of manual metal arc process coupled with the very high price of iron powders in India (typically Rs. 12,000 per ton against roughly Rs. 6,000 per ton of core wire material) has made this process less attractive from economic point of view and in fact has set up a 'reverse trend' in the present day context. Whereas it is expected that high deposition efficiency would lead to higher deposition rates, it is observed that weld time factor (defined as the ratio of arc time to total weld time) plays a very important role in MMA Process and this invariably slowed down welding speed. In addition, varying joint designs restrict the use of highest diameter electrode which is normally recommended to obtain the best results. Often it is found that the combination of these factors taken together with high price of electrode has not justified the economics to the extent they did in the advanced countries before the Gas Metal Arc Process took over. Salter found that 'Welders' discomfort increased with increased current and this put severe restrictions on welding speeds. Even with iron powder electrodes the deposition rate was still limited to approx. 1.1 to 5 kg/hr (100% arcing) in flat position and to 1.4 kg/hr in vertical or overhead position depending on the type of work. This is unsatisfactory compared to conventional GMA Process.

Nevertheless, iron powder electrodes both rutile and basic coated types have found some use in India particularly in shipbuilding and wagon manufacturing industries. One of the major shipyards in India is using 110% recovery rutile type electrode in vertical up position at a considerably faster welding speed and has been able to achieve economic targets within the limitations of MMA Process. In another instance, large length welds in wagon manufacture are manually carried out using basic coated 140% recovery electrodes with good results. Some case studies made in 1977 showed that a saving in the weld metal cost by approx. 6% was achievable but with considerable increase in cost of today's iron powder, it is doubtful whether this could be achieved any longer.

From the equipment point of view MMA Process should be and has been the most attractive to the user. The price of a transformer or even a rectifier is low and they require very little maintenance. The control is extremely simple and the welding has tremendous flexibility to negotiate with changes in welding position, material thickness and composition. In some instances resetting of controls can be remotely done by the welder himself without the help of any additional control cable. In such instances, he uses a 'pencil-like' electronic control rod which he can connect between electrode holder and the workpiece and this action automatically adjusts the welding current. Thus the welder can work at greater heights and at distances more than 100 metres or so from the power source and change electrode sizes without additional help.

To sum up, MMA Process using iron powder electrode could produce some useful economic results where

—welding by design has to have low duty cycle and welding lengths are essentially small.

—positional (vertical up or overhead) welding has to be carried out in the site e.g. at heights and in the open where Gas Metal Arc Process is not always useful.

—small length welding is spread over a wide area and in positions of poor accessibility.

3.0 Gas Metal Arc Welding (MIG/MAG)

While talking on economics, I would like to start this by quoting George Salter as this seems to be very appropriate under Indian context. He says 'The high mobility of MMA Process, more than anything else has set the pattern of fabrication shops and has led to the problems experienced with other processes of more limited scope which require changes in work flow pattern to achieve maximum productivity'. CO_2 Semi Automatic Welding Process in India today has caused more controversy in assessment of welding economics that any other process although everyone would admit that this process has obvious advantages over manual metal arc welding. A quick look at a typical example shown below will reflect the economics :

6 mm M. S. H. V. Fillet Weld

(Time for 30 metre weld)

	MIG	MMA	
	(1.2 mm at 300 A)	(6 mm at 275 A)	
Wire Consumed	6.3 Kg	80 Nos. Electrodes	
Gas Consumed	1.2 m^3	—	
Welding Speed	2.3 min/metre	5.9 min/metre	
Welding Time	70 min.	180 min	
Total Time	3.5 hr.	9 hr.	
		Low Hydrogen	Rutile
Cost of labour and O/H @ Rs. 40/- per hr.	140	360	360
Cost of Wire/Electrode	138.60	240	160
Cost of Gas	7.00	—	—
	285.60	600	520

Speed up by 150%
Cost down by 50% on Low Hydrogen and by 45% on Rutile

MIG saves approx. Rs. 10.50 per metre of weld against Low Hydrogen MMA

Price of MIG Consumables	— Rs. 22/- per kg.
Price of 6 mm Electrode	— Rs. 3/- each (Low Hydrogen)
Price of 6 mm Electrode	— Rs. 2/- each (Rutile)
Price of gas CO_2	— Rs. 5/- per kg.

Welders operating factor i.e. arc time to total time is taken as 33% for both processes though in practice using MIG results in higher operating factor.

Interestingly, cost of welding with high deposition efficiency iron powder electrode will be still higher.

The principal advantages of MIG Process lie in the fact that the welder has to only position the torch at a correct height from the weld pool and move hand in the direction of the weld. Unlike manual metal arc process, the welder does not have to skilfully manoeuvre the electrode on to the weld pool to maintain constant arc length and thereby the heat input. The filler metal is fed automatically and the current and voltages are continuously adjustable which ensures wide range of heat input and metal deposition. Frequent electrode change is not necesssary and chipping of slag is also nearly eliminated thereby saving considerable time particularly for multi-run welds. The other major advantage is the welders' training time is considerably reduced from that for MMA.

Even with these advantages, CO_2 welding has not replaced MMA in India to any appreciable extent. If we analyse some of the problems, the following scene emerges—

(a) Equipment Cost

A typical 400 amps. MIG equipment consisting of Transformer/Rectifier, a wire feeder unit and a torch with accessories would cost anything around Rs. 50,000 which is 4 to 5 times higher than an equivalent manual welding power source. There is a general reluctance to go in for this high initial investment. The fact that higher pay back more than offsets this investment is often not fully realised.

(b) Consumables Cost

Cost of consumables for the same quality of weld deposit may be 150% to 200% higher than the equivalent stick electrodes including stub end losses. In addition, cost of gas has to be added for MIG. But for applications with Low Hydrogen type electrodes it is observed that the cost of consumables for MIG today favourably compares with those of stick electrodes for the same quantity of weld deposit.

(c) Maintenance

CO_2 equipment needs periodic replacement of tips and nozzles, conduits and feed rolls and, at length, the entire welding torch and wire feeder. It has been observed that the annual cost of replacement and spares would be approx. 10% of the original cost of equipment.

In the example on economics shown, the depreciation charges, down time costs and the maintenance costs have not been indicated since for a 30 metre long single pass weld this will work out to be negligible. But it must be remembered that an arcing time factor of 33% *or above* must be *maintained to obtain the full benefit of this process* so as to offset the effects of depreciation and maintenance.

Many of the techno-economic advantages offered by MIG process have not been fully utilised in our country. These can be classified as follows :—

(*a*) *Welding conditions*—Very often it is observed that correct welding voltages/currents were not used.

As a result, the deposition rates were low. Considerable spatter with poor weld shapes as noticed. This often caused wire feeding problems, wire kinking, burn back or stubbed end situations. Ultimately the working life of torch necks and wire feeders are considerably reduced.

(*b*) *Duty Cycle*—In many instances, MIG equipment is used at very low duty cycle and often found to be lower than Manual Metal Arc Welding. One of the reasons is the users' failure to realise that *MIG equipment is rather inflexible compared to Manual Metal Arc Equipment*. The limitation is mainly due to the restricted length of the welding torch which is usually upto 5 metres from the wire feeder. The wire feeder needs to be moved around to extend this range.

The other factor that leads to low utilization is the *failure to programme the job to meet the high production capability* of this equipment. This is a fundamental problem with the factory where extensive planning is required to alter the production methods.

Poor maintenance, frequent component failures and general misuse are the other reasons for low performance of these machines.

Opposed to this scene, the technical advantages offered by MIG/CO_2 process clearly are :

—much higher deposition rate and higher welding speeds (typically 5-7 kg/hr of deposit is achievable)

—excellent control on heat input and weld pool for thin sheet metal welding. Low current CO_2 welding allows welding at much faster speed compared to gas welding with neater weld beads and lower heat distortion.

—reduction of deslagging improves duty cycle.

—use of argon rich gas mixture shielding which offers completely spatter free welds and consequently less weld cleaning.

Tasks Ahead

The need to make economic use of the MIG Process is certainly one of the most important tasks that lies ahead of us. The following areas are considered important :

—Training : Operators, maintenance personnel and welding engineers.

—Ascertaining duty cycle to ensure proper machine utilisation.

—Appraisal of welding economics, MIG vis-a-vis manual metal arc or gas welding (for thin sheet).

Salter lays down the following guidelines 'where CO_2 welding would show up greatest advantage is—

(a) Where work can be organised to feed the work to the machine.

(b) Where heavy welds have to be made in one area to make use of the high deposition rate of the process before moving the equipment.

(c) Where weld quality is not critical, so that semi skilled labour can be quickly trained.

(d) Where high quality work is available in such quantities as to make it worthwhile training craftsman and shopfloor managements and where welders can use the process sufficiently often to maintain their skill.

Flux Cored Wires

Solid wires with CO_2 or argon rich mixtures as shielding gases cannot cover as wide a range as manual electrodes. With the advent of flux cored wires it is now possible to extend MIG/MAG process to cover a wide area including the welding of mild steel, medium strength and high strength steels, alloy steels, creep resistance steels and so on. Flux cored wires have higher deposition rates and with suitable metallic alloying element in the flux it can be used on a range of hardfacing jobs as well. Typical deposition rate of 7-10. kg./hr. is achievable and it stands way above other welding processes as can be seen in the Fig. 1.

High deposition rates more than offset the increased cost of wire and the process stands only second to Submerged Arc Welding Process on deposition rates.

In India, the availability of indigenous flux cored wire is still very limited both in size and variety and time has now come where greater emphasis is given by the manufacturers in this direction. It should be noted here that any standard heavy duty MIG equipment is suitable for use with flux core wire. Typical comparison on deposition rates of MMA, CO_2 solid wire and flux cored wire is shown in Fig. 1.

4.0 Mechanised Welding

The principal disadvantages of manual and semi automatic welding stem out of the limitations imposed on the welder by the arc heat and skill required for manipulation. One way to overcome this problem is to mount the welding gun on some kind of traverse unit which would keep the arc steady and travel at an optimal speed.

With this method, mechanised welding is made possible on TIG, MIG, Submerged Arc, Continuous Coated Electrode, Electroslag and Electrogas Welding

Mechanised welding is classified in three main groups

(a) The horizontal flux shielded process-Submerged Arc Welding

(b) The all-position gas shielded process TIG & MIG

(c) The vertical process-Electroslag & Electrogas

Gas Metal Arc Welding in a narrow groove in mechanised horizontal welding situation (Narrow Gap Welding) is a recent addition and with the use of flux cored wires this is competing very effectively with Submerged Arc Process and in some instances has shown clear advantages on weld time and weld properties.

4.1 Horizontal Flux Shielded Welding—Submerged Arc Welding

It will be wrong to compare process of Submerged with say Manual or Semi Automatic Welding mainly because these processes are developed for different segments decided by material thickness, lengths of weld and weld position. While there exists a considerable amount of overlap between MMA and Semi Automatic GMA on economics in welding, Submerged Arc has very little overlap with GMA except in some mechanised welding applications using flux cored wires and of course when compared against Narrow Gap Welding. Although wire consumption and welding speeds vary from job to job, by and large the deposition rates in submerged arc conventional welding vary from 5.5 kg/hr for 2.5 mm dia electrode to approx. 20 kg/hr for a 3.3 mm dia electrode for a single wire use.

A lot of effort has been put forward to increase the deposition rate in submerged arc welding mainly to

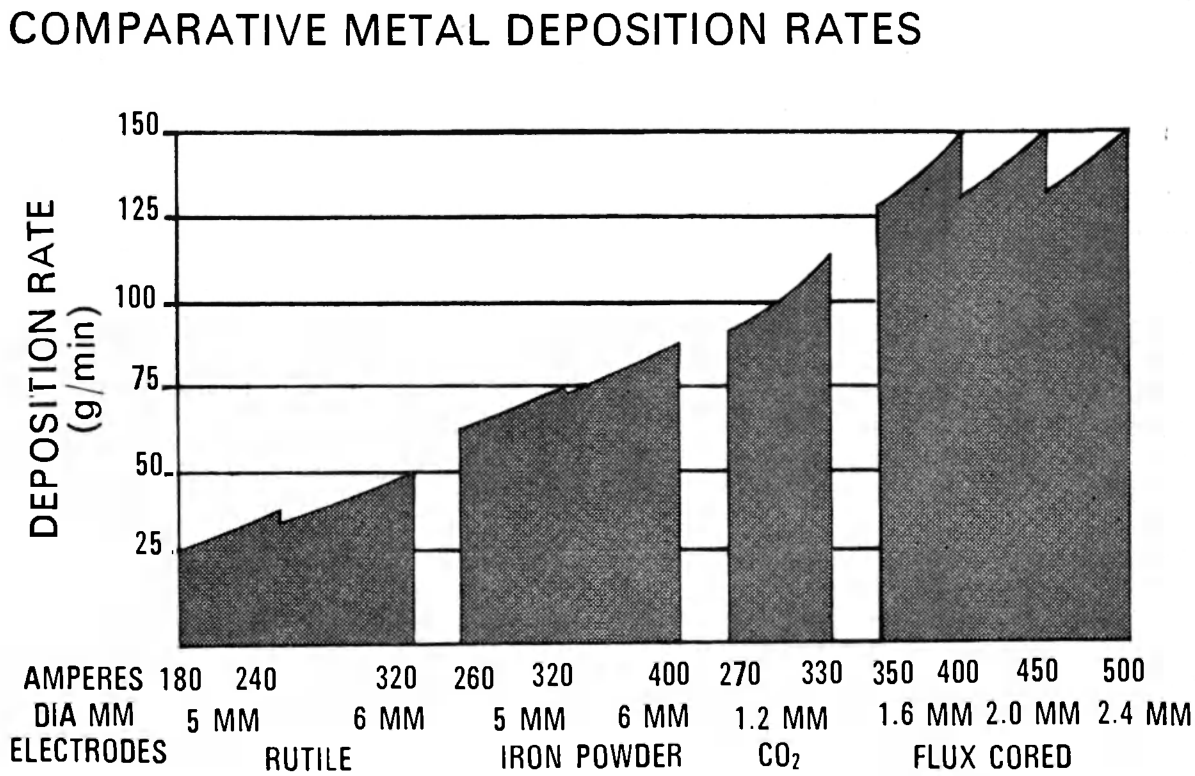

Fig. 1

cut down production time on the welding of thick to very thick walled vessels. These are briefly—

—High productive multi-wire tandem submerged arc welding.

—Use of increased stick out length and resultant I^2R heating before the wire melts into arc. Simultaneous use of negative polarity electrode.

—Use of cold filler wire addition into the weld pool, wire being supplied from an independent source.

—Use of hot filler wire addition into the weld pool. A separate AC power source heats up the additional filler wire through I^2R heating without an arc. The electrical circuit for I^2R heating is completed through the weld pool.

Each of approaches described above has specific economic advantages related to the weld joint requirements. There can be no general approach to achieve welding economics in all situations.

For example-Multiple wire S.A. welding can deposit twice as much weld metal but arc blow between two electrodes, excessive heat input and expensive capital outlay (where two power sources are needed) are the factors that go against this approach.

Use of larger stick out I^2R heating has no such problems but may result in inaccurate arc location or even less penetration in certain situations. Electrode negative polarity produces higher deposition rate but certainly has reduced penetration.

Cold filler wire addition technique may suffer from cold lapping or lack of fusion problems and reduced penetration if the heat input is not sufficient.

Hot wire addition certainly offers high efficiency possibilities but will have to use a relatively more expensive equipment although this will not be as high as the tandem system.

Mohanty of WRI, Trichy in his work on C-Mn steel pipes of 16-40 mm thickness using hot wire technique has shown that it is possible to achieve 100% extra deposition but for good penetration and bead shapes it is desirable to reduce the additional deposition to about 55-70%.

He also observed that with hot wire addition, the saving on time was 30% compared to single wire SAW. On 20 mm plate the saving on total cost of weld was approx 8%.

On 40 mm plate this saving is approx. 6.5% compared to single wire SAW and approx. 9% compared to 2 wire tandem welding.

4.2 All Position Mechanised Gas Shielded Welding-TIG/MIG

While conventional mechanisation has certainly shown improvement in the overall economics of both TIG and MIG/MAG Process wherever the joint designs permitted the use of these, it is perhaps the use of Multiaxes Manipulators or Welding Robots that has created the biggest ever impact on the welding economy in the advanced countries wherever gas shielded processes are used.

These welding robots along with programmable manipulation of the head or job or both can work either in open loop situation or in conjunction with secondary sensors in a closed loop to accurately locate the joint in relation to the torch. They usually use conventional power sources and wire feeders but with provisions of calling up pre-programmed welding conditions depending on the location of weld, the material thickness and joint geometry.

On mechanised TIG Welding, a fully automatic system has been introduced where a welder has been totally replaced by electronic device as a part of the 'weld quality feed back loop'. Sensors are again used to measure the heat input, quality parameters and penetration level and control is automatically effected to achieve defect free welds throughout. These systems are generally found inexpensive.

In India, nothing much has been achieved in these directions but some of these are bound to come and once introduced will substantially influence the welding economy.

4.3 Vertical Mechanised Welding

Electroslag and Electrogas—
Electroslag uses solid consumable wire fed through a copper guide. The wire melts in the heat developed by passing electricity through the conductive slag which is held with the molten weld in the joint gap by water cooled shoes. In another form it is known as consumable nozzle welding where this wire is fed through a tubular or composite steel guide and the guide itself is consumed with the electrode. There is no arc between the electrode and the molten metal.

The equipment used is very similar to S/A Welding Equipment but with capacities to deliver much higher currents at 100% duty cycle.

Electrogas uses flux cored wires producing an arc between tip of wire and molten pool in a CO_2 environment. Flux cored wire is fed continuously and water cooled copper shoes slide as the weld proceeds. Thus welding is carried out vertically in one pass.

Electroslag process can be used on plate from 20 mm to more than 300 mm thickness whereas Electrogas is recommended for use with plates from 12.0 mm to 40 mm thickness.

The outstanding production advantage of these processes are that high metal deposition rates and welding speeds can be obtained in a position where other arc proceses are normally restricted to approx. 1.5 kg./hr. Typically the deposition rates can be 11-25 kg/hr. in a vertical position at welding speeds 6-8 metres/hr.

There are of course two major disadvantages which have severely restricted the use of these processes—

—Only vertical welding is allowed which often leads to difficulty in long length joints.

—Processes usually result in poor impact property (due to slow heating) in both weld metal and heat affected zones.

5.0 Weld Aids

Rotators, Production Manipulators, Positioners, Booms, Side Beam Carriages of a range of specifications are now available to facilitate easy handling of the work in relation to welding head. The importance of these in reducing the cycle time of welding and improving arcing factor for overall welding economy can never be over-emphasised. It will be interesting to see large scale uses of some of these work handling equipment even on MMA process which should be very appropriate

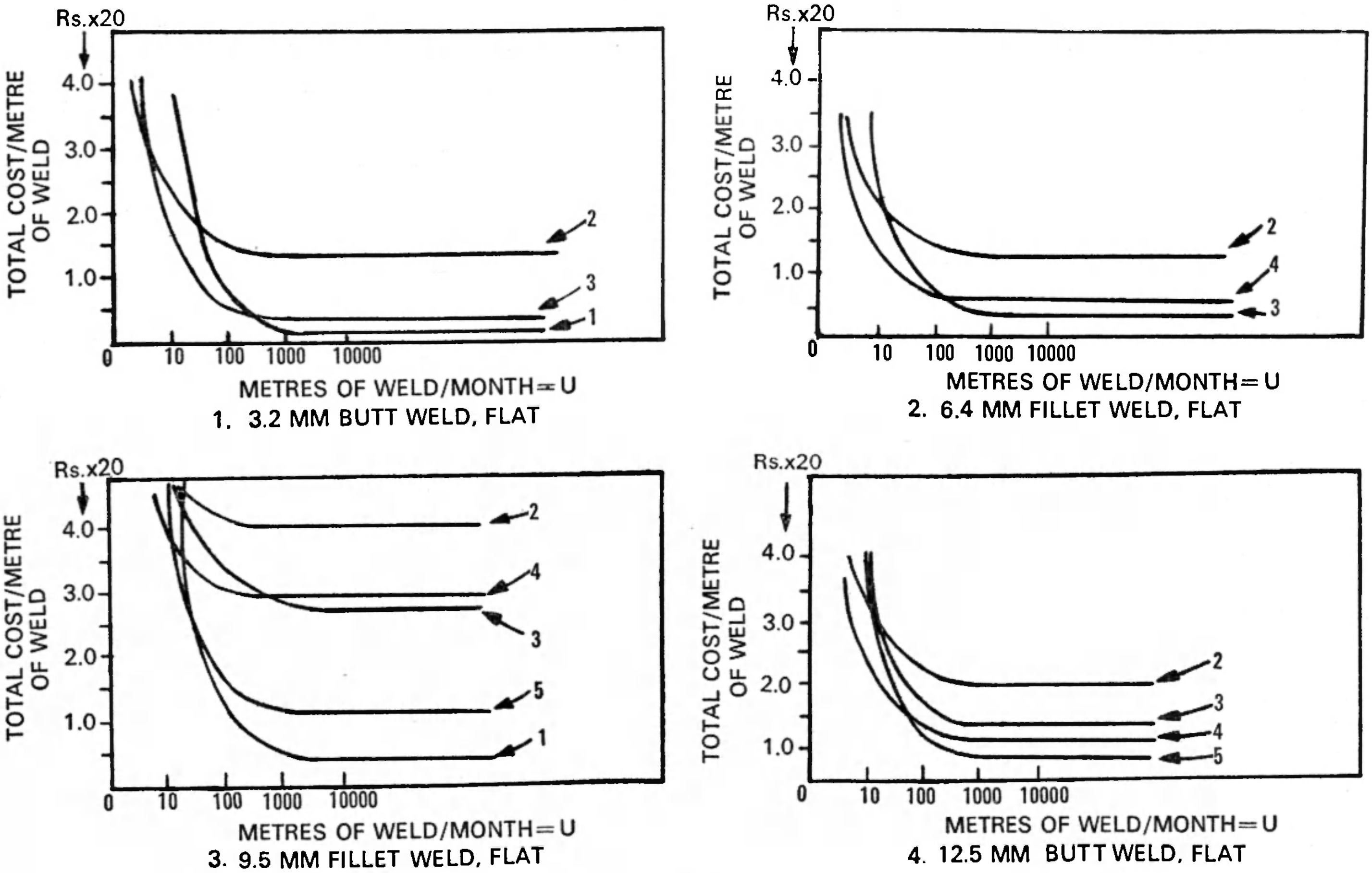

Fig. 2

in India. A simple positioner can convert a positional weld to a downhand welding situation with obvious economic advantage. A circumferential weld of a flange to pipe or surfacing on a valve seat can be easily carried out with the help of a turn table and stick electrodes can be used even if GMA processes are not considered. The pay off is practically immediate if optimum machine utilisation is ensured.

In India use of these weld aids has not grown appreciably. It is hoped that with the introduction of faster processes such as MIG/CO_2 etc. use of these aids will grow and these two when combined can achieve remarkable results.

Cost per metre of weld length, for varying lengths covering all processes are shown in Figure 2. From these figures it will be seen that to get the best advantage there exists a minimum length of weld described in metres/month.

Conclusions

Economics in welding is mainly derived from the numerical data on production time, production costs, machine utilisation, spares and maintenance costs, utilisation of consumables through selection of correct welding conditions and procedures and so on. These figures are derived after the technicalities of a particular welding process are sorted out in relation to the requirement of production welding. This can be very complex if the variables are considered all at a time.

Since equipment and consumables continue to offer the major component to process economics it is important to ensure that best deposition rates are consistently achieved with minimum idle time. Equipment reliability particularly when semi automatic and fully mechanised systems are used combined with free availability of consumables of consistent quality is the key to atleast partially achieve the economic targets in a total welding setup.

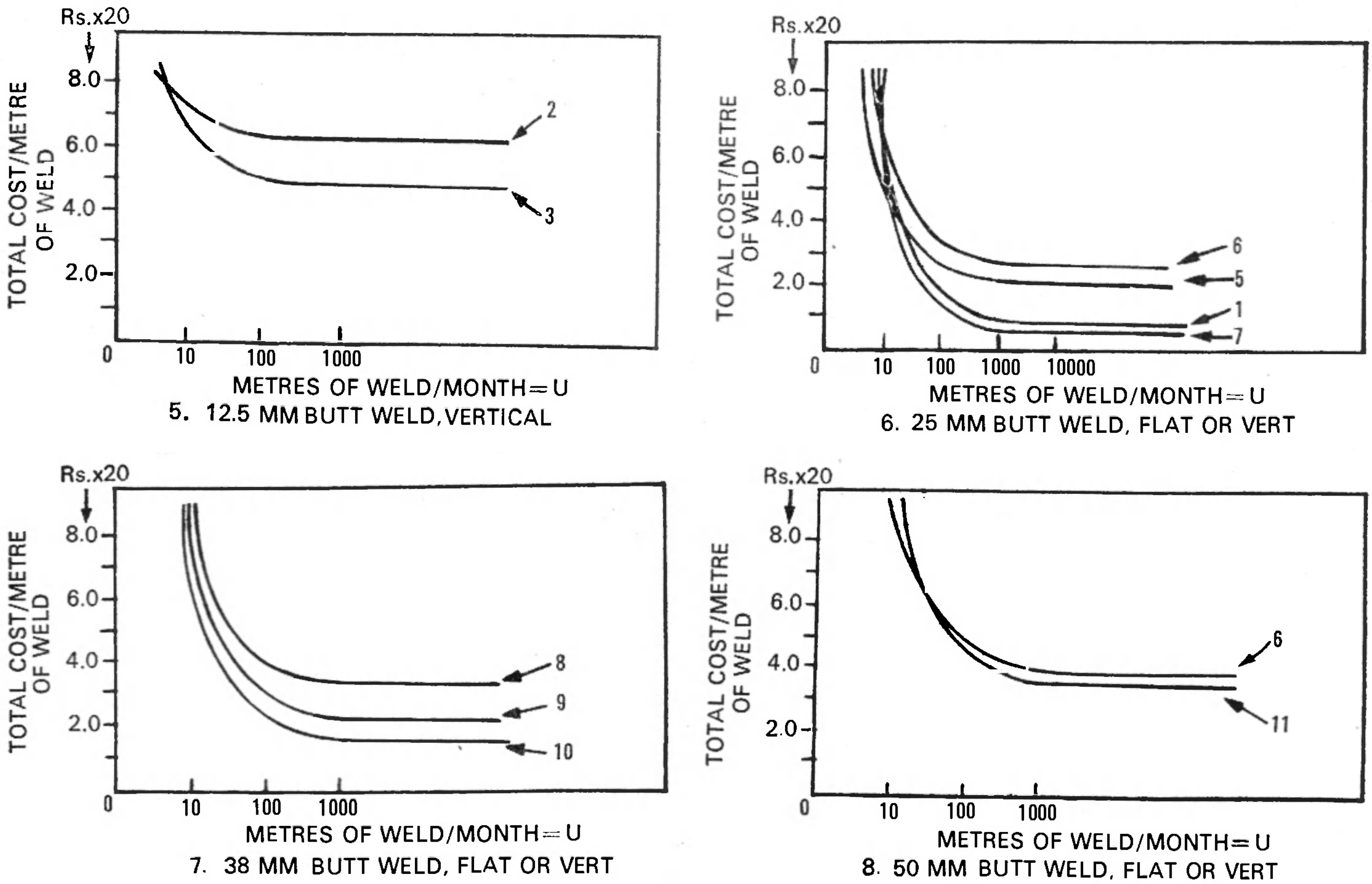

Fig. 2

Comparative cost/metre of weld, covering all conventional welding processes.

KEY TO FIGURE 2 (1 to 8)

1. SUBMERGED ARC ONE PASS
2. MANUAL, RUTILE
3. SEMI-AUTOMATIC MIG
4. MANUAL, RUTILE/IRON POWDER
5. SEMI AUTOMATIC FLUX CORE/CO_2
6. CONSUMABLE NOZZLE
7. SUBMERGED-ARC 2 PASS
8. CONVENTIONAL CONSUMABLE NOZZLE
9. SUBMERGED-ARC 3 PASS
10. NARROW GAP CONSUMABLE NOZZLE
11. SUBMERGED-ARC 5 PASS

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WELD SPATTER

According to the President of the Catterpillar Tractor Company of USA, the firm has been saving $ 1 million annually since it converted from English units to metric. Mainly the following factors helped :

—No need to redesign products for overseas plants.

—A reduction in the number of sizes of raw steel product, leading to fewer and larger orders, which in turn means better pricing and smaller inventory.

—Better design selection resulting from a logical sequence of sizes.

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